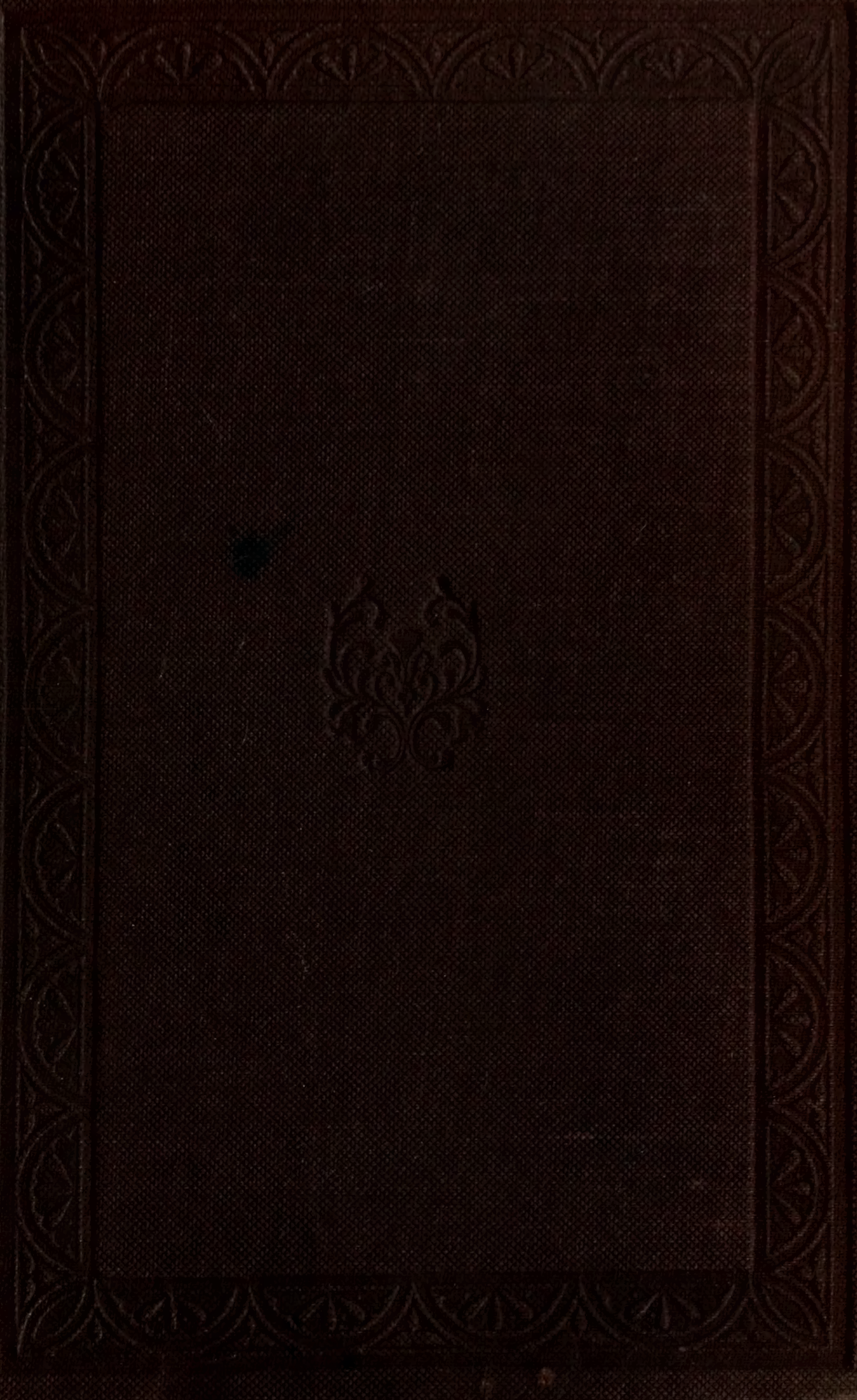

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Presd by the Institution

A

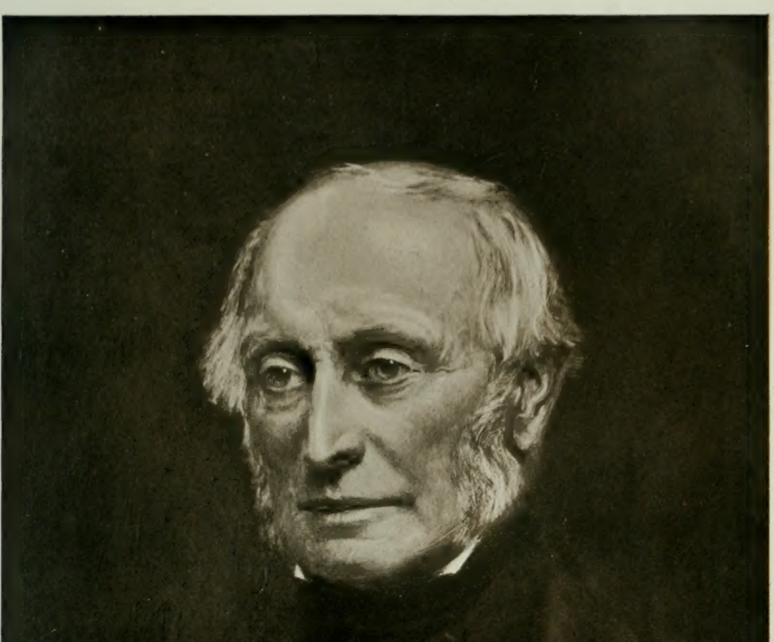
LORD ARMSTRONG, C.B.

(1810—1900.)

President 1861—1862, and 1869.

William George Armstrong was born in Newcastle-on-Tyne on the 26th November 1810. He was articled to a firm of solicitors, and in 1834 became junior partner; but at the age of 36 he abandoned the profession, and in 1847 formed a partnership with Messrs. Donkin, Cruddas, Potter and Lambert, and established a small engineering business at Elswick. While a solicitor he devoted himself to the construction of hydraulic machinery, making use of the water-works pressure, and his invention of the hydraulic accumulator in 1850 gave a great impetus to the employment of such plant. The effective use of heavy guns by the Russians at Inkerman turned his attention to the improvement of ordnance, and the type of built-up rifled gun, with which his name will always be associated, was invented. His labours in this direction resulted in the development of the great Elswick Works. He was appointed Director of Rifled Ordnance in 1859, a position which he held until 1863. He received the honour of Knighthood, was made a Companion of the Bath, and in 1887 was created a Baron. He was also the recipient of decorations and Orders of Knighthood from many foreign Sovereigns. He died on the 27th December 1900.

Lord Armstrong became a Member of this Institution in 1858, was elected a Vice-President in 1859, and was President in 1861 and 1862, and again in 1869.



W. G. Armstrong

THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1912.

PARTS 1–2.

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STOREY'S GATE, ST. JAMES'S PARK, LONDON, S.W.

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CONTENTS.

1912.

PARTS 1–2.

PAGE

Portrait of The Right Hon. Lord ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., *President* 1861–2, 1869.
List of Past-Presidents iv
List of Officers v
Articles and By-laws vii
PROCEEDINGS, JANUARY MEETING.—Decease of S. W. Johnson . . 1
Nomination of Candidates for Council 2
Election of Members and Transferences 3
"Evolution of the Turbine-Pump"; by E. Hopkinson and A. E. L. Chorlton (Plates 1–3) 7
"Researches at National Physical Laboratory"; *Lecture* by T. E. Stanton 71
PROCEEDINGS, 65TH ANNUAL GENERAL MEETING, 16th February.—
Business 81
Election of Officers 82
Appointment of Auditor 84
Annual Report 85
Draft Scheme for Associate Membership Examinations 124
PROCEEDINGS, MARCH MEETING.—Decease of T. P. Reay . . . 173
Council Appointments 173
Election of Members and Transferences 174
"Diesel Oil-Engine"; by R. Diesel (Plates 4–8) 179
"Diesel Oil-Engine"; by H. S. Pursey 281
Memoirs 299
PROCEEDINGS, APRIL MEETING.—Election of Members and Transferences 311
Anniversary Dinner 315
PROCEEDINGS, 3RD MAY.—Business 318
"Tenth Alloys Report"; by W. Rosenhain and S. L. Archbutt (Plates 9–22) 319
"Air-Supply to Internal-Combustion Engines"; by W. Watson and H. Schofield 517
Memoirs 553
Index to Proceedings 1912, Parts 1–2 563
PLATES 1–22.

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. (*Deceased* 1903.)

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79. (*Deceased* 1902.)

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)

Jeremiah Head, 1885–86. (*Deceased* 1899.)

Sir Edward H. Carbutt, Bart., 1887–88. (*Deceased* 1905.)

Charles Cochrane, 1889. (*Deceased* 1898.)

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

E. Windsor Richards, 1896–97.

Samuel Waite Johnson, 1898. (*Deceased* 1912.)

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900.

William H. Maw, LL.D., 1901–02.

J. Hartley Wicksteed, 1903–04.

Edward P. Martin, 1905–06. (*Deceased* 1910.)

T. Hurry Riches, 1907–08. (*Deceased* 1911.)

John A. F. Aspinall, 1909–10.

The Institution of Mechanical Engineers.

OFFICERS.

1912.

PRESIDENT.

Edward B. Ellington,	London.

PAST-PRESIDENTS.

John A. F. Aspinall,	Manchester.
Sir Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
William H. Maw, LL.D.,	London.
E. Windsor Richards,	Caerleon.
Percy G. B. Westmacott,	Ascot.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

VICE-PRESIDENTS.

Henry Davey,	Ewell.
Sir H. Frederick Donaldson, K.C.B.,	Woolwich.
Michael Longridge,	Manchester.
The Right Hon. Lord Merthyr, K.C.V.O.,	Aberdare.
A. T. Tannett-Walker,	Leeds.
Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.

MEMBERS OF COUNCIL.

William H. Allen,	Bedford.
Archibald Barr, D.Sc.,	Glasgow.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S.,	London.
George J. Churchward,	Swindon.
Dugald Clerk, F.R.S.,	London.
Sir Robert A. Hadfield, D.Met., F.R.S.,	Sheffield.
H. S. Hele-Shaw, LL.D., F.R.S.,	London.
Edward Hopkinson, D.Sc.,	Manchester.
J. Rossiter Hoyle,	Sheffield.
George Hughes,	Horwich.
Henry A. Ivatt,	Hayward's Heath.
Henry Lea,	Birmingham.
Robert Matthews,	Manchester.
Donald B. Morison,	Hartlepool.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S.,	London.
William H. Patchell,	London.
The Right Hon. Lord Pirrie, K.P., P.C., LL.D.,	Belfast.
Walter Pitt,	Bath.
Mark H. Robinson,	London.
Captain H. Riall Sankey, R.E., ret.,	London.
Wilson Worsdell,	Ascot.

HON. TREASURER.

Arthur Huson, F.Inst.B.

AUDITOR.

Robert A. McLean, F.C.A.

SECRETARY.

Edgar Worthington,
The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W.
Telegraphic Address:—*Mech, London.* Telephone:—*Victoria*, 4564.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

(*Article* 23 *revised March* 1902.)

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, twenty-one ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and seven Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree otherwise among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from His Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1907.)

MEMBERS.

1. No Candidate shall be elected a Member, or be transferred into the class of Members, unless he is at least 30 years of age, and has produced evidence, to the satisfaction of the Council, either

I. That he—

(a) Has received a good general and scientific education;

(b) Has been regularly trained as a Mechanical Engineer; and

(c) Has been engaged for a sufficient period in an important position of independent responsibility in the direction of engineering work:

Or II. That he—

(d) Has received a thorough scientific education;

(e) Has had sufficient practical experience as a Mechanical Engineer; and

(f) Has for a sufficient period held an important position of independent responsibility in connection with engineering work:

Or III. That he—

(g) Has attained to a position of such eminence in the profession, or in the direction of engineering work, as to qualify him, in the opinion of the Council, for the distinction of Membership.

ASSOCIATE MEMBERS.

2. No Candidate shall be elected an Associate Member, unless he is at least 25 years of age, and has produced evidence, to the satisfaction of the Council, either

I. That he—
- (a) Has received a good general education;
- (b) Has been regularly trained as a Mechanical Engineer; and
- (c) Has had subsequent employment for at least one year in a responsible position in the direction or design of engineering work, and is actually so engaged at the time of his application for Election:

Or II. That he—
- (d) Has received a good general and scientific education;
- (e) Has had sufficient practical experience as a Mechanical Engineer; and
- (f) Has had subsequent employment for at least one year in a responsible position in the direction or design of engineering work, and is actually so engaged at the time of his application for Election.

GRADUATES.

3. Graduates shall be persons not under 18 years of age, who shall satisfy the Council that they have received a good general education, and have received, or are receiving, regular training as Mechanical Engineers, and that they have received, or intend to obtain, sufficient practical and scientific training to fit them for employment in responsible positions as Mechanical Engineers. No person shall be elected a Graduate after the age of 25 years.

Graduates may not continue as such if they cease to follow the profession of Engineering, nor in any case beyond the age of 28 years.

ASSOCIATES.

4. Associates shall be persons of at least 30 years of age, who not being Mechanical Engineers by profession, yet by reason of their attainments in science, or in any of the arts allied to, or having interests in common with, Engineering, may be deemed by the Council to be worthy of the distinction of Associateship.

TRANSFERENCE.

5. At the discretion of the Council properly qualified Associate Members may on application be transferred to the class of Members, and properly qualified Associates may be transferred to the classes of Associate Members or Members.

HONORARY LIFE MEMBERS.

6. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific attainments.

PRIVILEGES OF MEMBERSHIP.

7. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of, and the privilege to attend, all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

8. The abbreviated distinctive Titles for indicating the connection with the Institution, of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

9. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

10. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

11. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional Subscription for the current year, and £1 additional Entrance Fee.

12. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee.

13. Each Associate shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional Subscription or Entrance Fee. If transferred direct to the class of Members, he shall pay on transference 10*s*. additional Subscription for the current year, and £1 additional Entrance Fee.

14. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of each Member, Associate Member, Graduate, and Associate, shall date from the 1st day of January in the year of his election, and shall, except in the cases provided for by By-law 15, entitle him to the Proceedings published during that year.

15. In the case of each Member, Associate Member, Graduate, or Associate, elected in the last three months of any year, the first Subscription shall cover both the year of Election and the succeeding year, but shall only entitle the person elected to the Proceedings published after his Election.

16. Any Member, Associate Member, or Associate, whose Subscription is not in arrear, may at any time compound for his Subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in arrear with their Subscriptions more than twelve months, and whose Subscriptions have not been remitted by the Council as hereinafter provided. (By-law 18.)

18. The Council may at their discretion reduce or remit the Annual Subscription, or the arrears of Annual Subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the Annual Subscription provided by these By-laws.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

19. Every recommendation for Election shall be in accordance with Form A or Form B in the Appendix, and shall be forwarded to the Secretary who shall lay it before the Council. The Form A must be signed by the Candidate and by not less than five Members or Associate Members, and the Form B by the Candidate and by not less than three Members or Associate Members.

20. All Elections shall take place by Ballot of the Members and Associate Members, four-fifths of the votes given being necessary for Election.

21. Every recommendation for Election shall be considered by the Council. The Ballot Lists shall contain only such names in each class as are approved by the Council for Election. Each List of approved Candidates shall be signed by the Chairman of the Council Meeting authorising its issue. The Ballot Lists shall be classified, and shall specify the name, occupation and address of each Candidate, and the names of his Proposer and Seconder; they shall be sent to Members and Associate Members only, and shall be opened by, or in the presence of, a Committee appointed for that purpose by the Council. The Committee shall report the result of the Ballot to the Council.

22. The result of each Ballot shall be declared at the next General Meeting.

23. When a Candidate is elected, the Secretary shall give him notice thereof according to Forms D or E in the Appendix; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription.

24. In case of non-Election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

25. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members, or to that of Members, shall forward to the Secretary a recommendation, according to Form C in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the Council. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F; but his name shall not be added to the list of Members or Associate Members until he shall have paid the additional Entrance Fee (if any), and the additional Subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

26. At the General Meeting preceding the Annual General Meeting, the Council are to present a list of Members nominated by them. Any Member or Associate Member shall then be entitled to add to the list of Candidates. A Ballot List of the proposed names shall be forwarded to each Member and Associate Member. The Ballot Lists shall be opened only on the day of the Annual General Meeting, in the presence of the Council, by a Committee appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

27. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed, on the recommendation of the Council, by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

28. The Secretary of the Institution shall be appointed, on the recommendation of the Council, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications

that he may be ordered to read; to superintend the publication of such Papers as the Council may direct; to have the charge of the Institution building and library; to direct the collection of the Subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council), and be responsible for, all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

30. The Auditor shall be a Fellow of the Institute of Chartered Accountants, and shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members. The yearly Accounts, after being duly audited, shall be presented by the Council to the Annual General Meeting.

MEETINGS.

31. Every Paper shall be submitted to the Council for approval, and after approval shall be read at a General Meeting, or shall be printed in the Proceedings without having been read at a General Meeting, as may be directed by the Council.

32. The proceedings at the General Meetings shall, as far as practicable, conform to the following order:—

1st. The Chair shall be taken at such hour as the Council may direct.

2nd. The Minutes of the previous Meeting shall be read by the Secretary, and, after being approved as correct, shall be signed by the Chairman.

3rd. The result of the examination of the Ballot Lists shall be declared to the Meeting, and the names of the Members, Associate Members, Graduates, and Associates elected shall be announced. Any Transferences made by the Council since the last Meeting shall also be announced.

4th. Papers approved by the Council shall be read by the Secretary, or by the Author, as may be directed by the Council.

33. Each Member or Associate Member shall have the privilege of introducing one friend to any of the General Meetings; but, during such portion of any Meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

34. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

35. The discussion upon any Paper may be adjourned at the discretion of the Chairman.

36. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

MISCELLANEOUS.

37. The President shall *ex officio* be a member of all Committees of the Council.

38. All Communications to the Institution, unless declined, shall be the property of the Institution, and shall be published only by the authority of the Council.

39. None of the property of the Institution shall be taken out of the premises of the Institution without the consent of the Council.

40. All Donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

41. Advance copies of Papers to be read at the Meetings may be sent to members on application to the Secretary.

42. All Books, Drawings, Communications, etc., shall be accessible to the members of the Institution at all reasonable times.

43. Graduates and Associates elected prior to 1893 shall, notwithstanding anything in these By-laws contained, retain the privileges set out in the By-laws as revised in January 1890.

APPENDIX.

FORM A.

(Proposal as Member, Associate Member, or Associate.)

Name in full..

Designation or Occupation...

Business Address...

being...................years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our *personal knowledge*, and (at least) three other supporters, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this...........day of...

Five Members' or Associate Members' Signatures are required.

Proposed from *personal knowledge* by...

Seconded from *personal knowledge* by...

Supported from *personal knowledge* by..

Supported from *trustworthy information* by.......................................

Those who sign this Form are desired to append their initials to the portions of the statement of which they have personal knowledge.

ENGAGEMENT.

I, the undersigned, do hereby agree that, in the event of my election as Member, Associate Member, or Associate, I will be governed by the regulations of The Institution of Mechanical Engineers as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Signature of Candidate ....

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	* Initials of Supporters.
Date and Place of Birth..	....
General Education (with dates)..	....
Technical Education (with dates, subjects taken, and successes gained)................................	....
Apprenticeship (with dates, and particulars of training received)	....
Subsequent Career (with dates, and positions held)................	....
Brief Details of most important Mechanical Engineering work for which Candidate has been personally responsible	....
Membership in other Societies..	....

Signature of Candidate..

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* Members supporting this proposal are requested to place their initials against those particulars of the Candidate's career of which they have personal knowledge.

FORM B.

(Proposal as Graduate.)

Name in full..

Designation or Occupation...

Business Address..

Address for communications...

being.......................years of age, and desirous of becoming a Graduate of The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our *personal knowledge*, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this...........day of...

Three Members' or Associate Members' Signatures are required.

Proposed from *personal knowledge* by..

Seconded from *personal knowledge* by..

Supported by..

Date and Place of Birth...

General Education (with dates)..

Technical Education (with dates, subjects taken, and successes gained).........

....

Apprenticeship (with dates, and particulars of training received).................

....

Subsequent Career (with dates, and positions held)...............................

....

Signature of Candidate..

I, the undersigned, do hereby agree that in the event of my election I will be governed during my Graduateship by the regulations of The Institution of Mechanical Engineers, as they are now formed or as they may hereafter be altered: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Signature of Candidate ....

FORM C.

(Proposal for Transference.)

Name in full..

Designation or Occupation...

Business Address...

being..............years of age, and desirous of being transferred into the class of..........................of The Institution of Mechanical Engineers, we, the undersigned, from our *personal knowledge*, recommend him as a proper person to be so transferred by the Council.

Witness our hands, this............day of...

Five Members' or Associate Members' Signatures are required, from personal knowledge.

(Members of the Council do not sign this form.)

Proposed by..

Seconded by..

Those who sign this Form are desired to append their initials to the portions of the statement of which they have personal knowledge.

	* Initials of Supporters.
Qualifications (since joining the Institution).......................	....
....	....
Signature of Candidate..	

* Members supporting this proposal are requested to place their initials against those particulars of the Candidate's career of which they have personal knowledge.

FORM D.

Sir,—I have the pleasure to inform you that on the......................... you were elected a.................of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that your Entrance Fee and first Annual Subscription be paid, the amounts of which are...............and..................respectively. If these be not received within two months from the present date, the Election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

Sir,—I have the pleasure to inform you that on the.......................... you were elected a **Graduate** of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that your first Annual Subscription be paid, the amount of which is £1 10*s.* 0*d.* If this be not received within two months from the present date, the Election will become void.

I am, Sir, Your obedient servant,
Secretary.

FORM F.

Sir,—I have the pleasure to inform you that the Council have approved of your being transferred to the class of.......................of The Institution of Mechanical Engineers. For the ratification of your Transference in conformity with the rules, it is requisite that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are..................and..................respectively. If these be not received within two months from the present date, the Transference will become void.

I am, Sir, Your obedient servant,
Secretary.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1912.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 19th January 1912, at Eight o'clock p.m.; **EDWARD B. ELLINGTON**, Esq., President, in the chair.

The PRESIDENT regretted to have to announce, although probably the members were already aware of the fact, that a respected Past-President of the Institution, Mr. Samuel Waite Johnson, had passed away in the course of the last few days. Mr. Johnson was so well known to members, and had given such long service to the Institution, that it was perhaps unnecessary to remind the members of the important work that he had done. He was elected a Member in 1861, became a Member of Council in 1884, a Vice-President in 1895, and was President in 1898. A suitable letter of condolence had been sent to his daughter by the Council that afternoon, with which letter he was sure the members would desire to be associated.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that, in accordance with Article 23, the President, two Vice-Presidents, and seven Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

President.

Edward B. Ellington,	London.

Vice-Presidents.

Arthur Keen,	Birmingham.
The Lord Merthyr, K.C.V.O.,	Aberdare.

Members of Council.

Archibald Barr, D.Sc.,	Glasgow.
George J. Churchward,	Swindon.
William H. Patchell,	London.
Walter Pitt,	Bath.
Mark Robinson,	London.
Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.
Wilson Worsdell,	Ascot.

All of these had offered themselves for re-election, with the exception of Mr. Arthur Keen, Vice-President, and were nominated by the Council.

The following Nominations were also made by the Council for the election at the Annual General Meeting:—

For Vice-President.

Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.

For Members of Council.

Election as Member.		
1899.	John Dewrance,	London.
1887.	Donald B. Morison,	Hartlepool.
1888.	The Rt. Hon. Lord Pirrie, K.P., P.C., LL.D.,	Belfast.

All of the foregoing had consented to the Nomination.

The President reminded the Meeting that, according to By-law 26, any Member or Associate Member was then entitled to add to the list of candidates.

No other names being added, the President announced that the foregoing names would accordingly constitute the nomination list for the Election of Officers at the Annual General Meeting.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and that the following sixty-nine candidates were found to be duly elected:—

MEMBERS.

Colborne, Thomas,	Glasgow.
Creak, Robert Brown,	Manchester.
Faulkner, James,	Perth, W. Aus.
Gall, John,	Buenos Aires.
Goldingham, Arthur Hugh,	New York.
Goslett, Francis Joseph,	Gwalior.
Harbottle, John,	Kimberley.
Hardisty, John,	Bolton.
McLaren, Robert,	Rosario de Santa Fé.
McNeil, William,	Glasgow.
Metcalfe, Henry Francis,	Sibpur.
Richardson, Ernest Lowther,	Podanur, India.
Webber, Wyatt,	Calcutta.

ASSOCIATE MEMBERS.

Allin, Henry Philip,	Cambridge.
Bousfield, Arthur Joseph,	St. Peter's, Kent.
Brown, George Smith,	Aberdeen.
Collingham, Edwin Basil,	Beeston, Notts.
Crabtree, Wilfrid Smart,	Middlesbrough.
Cronk, Norman Tylee,	Montreal.
De Gruchy, William Arthur,	Melbourne.
Dover, Henry James,	London.
Goddard, Harold Percy,	Rio de Janeiro.
Grandage, Norman Alexander,	Chester.
Gray, Archibald,	Guildford.
Greenshields, Charles David,	Hubli.
Hasendahl, Walther,	London.
Henriques, Philip Quixano,	Birkenhead.
Howard, Percy,	Singapore.
Kerr, Robert Price,	Gateshead.

Kirby, Joseph Pearson,	Bradford.
McCallum, William Alexander,	Buenos Aires.
Mackenzie, George Samuel,	London.
Minnitt, John Anson,	Bombay.
Moir, William Robertson,	Basrah, Turkish Arabia.
Morgan, William Henry,	London.
Oxley, John Herbert Walter,	Stroud, Glos.
Pooley, James Price Favell,	Calcutta.
Price, William John,	El Paso, Texas.
Rhodes, William Foster,	Stockport.
Richards, William John,	Rotherham.
Robinson, Alfred Ernest,	Bombay.
Robinson, Percy Malcolm,	Singapore.
Shaw, William Morris,	Lymm.
Sinclair, Herbert,	Calcutta.
Singleton, Samuel Martin,	London.
Smith, Hubert Elwell,	London.
Tibbenham, Lewis John,	Stowmarket.
Ventress, Ernest William Stannard,	London.
Walker, Francis Henry,	Bradford.
Whitaker, August,	Bradford.

GRADUATES.

Barr, James Archibald,	Rangoon.
Cousin, Arthur Norman,	London.
Crofton, Edward Vivian Morgan,	London.
Green, Frank Menzies,	London.
Heron, Sam Dalziel,	London.
Okey, William Ewart,	Bournemouth.
Pitt, Robert Brindley,	Bath.
Preedy, Charles Harold,	Camborne.
Rabines, Maximino Alfredo,	Liverpool.
Robertson, Cyril Ernest,	Chelmsford.
Ruscoe, Jack Osmund,	London.
Sidahmed, Moharrem Sabet,	Kafr-el-Cheikh.
Spink, Reginald John,	Leeds.

Stewart, James Cleghorn, . .	London.
Walker, Norman Hay, . . .	Hednesford.
Wilson, John, ...	London.
Womersley, William Dobson, . .	Halifax.
Woodward, Ralph, ...	Weston-super-Mare.
Zolmer, William Victor, . . .	Croydon.

Transferences.

The President announced that the following three Transferences had been made by the Council:—

Associate Members to Members.

Gauvain, William Percival, . .	Waihi, N.Z.
Henderson, Philip, . . .	London.
Wilson, Richard Dawes, . .	Kew, Surrey.

The following Paper was read and discussed:—

"The Evolution and present Development of the Turbine-Pump"; by Edward Hopkinson, D.Sc., *Member of Council*, and Alan E. L. Chorlton, *Member*, of Manchester.

The Meeting terminated at Ten o'clock. The attendance was 159 Members and 83 Visitors.

THE EVOLUTION AND PRESENT DEVELOPMENT OF THE TURBINE-PUMP.

BY EDWARD HOPKINSON, D.Sc., *Member of Council*,
AND ALAN E. L. CHORLTON, *Member*, OF MANCHESTER.

To-day the turbine principle seems to be the accepted ideal of almost all primary machines. It would appear that the age of the reciprocating engine, for the various duties of mechanical engineering, is passing, and that the rotary engine of the turbine type is steadily taking its place. In that of steam prime-movers it has, perhaps, already taken the lead over the reciprocating type, and the engine of Watt must now be relegated to second place. In other fields and duties its progress to date is so great as to warrant the surmise that at no distant time a similar comparison of precedence will be made. In no domain, perhaps, has the turbine rotary principle achieved greater success in the last few years than that of high-lift pumping, though the realization of its possibilities for such duties, by some, is perhaps as old or older than the steam-turbine itself. Still its general acceptance as correct engineering practice is only a matter of the last five years.

At the present time the use of the Turbine-Pump has become so extended that it is difficult to find services to which it cannot be advantageously applied. It will no doubt, therefore, be a matter of interest to trace the evolution and development of machines of this design, and this, perhaps, cannot be better done within the limits of a single Paper and the time available than by considering in particular one type only, and which the authors believe to be *the* original. As a description of the commercial application of the steam-turbine is a history of the Parsons machine, so that of the turbine-pump can be adequately portrayed by an account of the evolution of the Osborne Reynolds Pump.

The rotary machine for raising water in the form of a centrifugal pump is a very old contrivance, and was the forerunner of pumps of the turbine type. At the beginning of the eighteenth century, Denis Papin, the French physician and physicist, afterwards a Fellow of the Royal Society, communicated to the Society a Paper * in which he describes how "being busy for a coal mine, which has been left off, because of the impurity of the air," he had devised improvements in the Hessian bellows with a view to applying them both to wind and water. His improved apparatus consisted of radial wings caused to revolve about an axis in a cylindrical chamber of which the portion external to the wheel was of a spiral shape. His drawings show clearly the volute casing of the modern centrifugal pump. Papin had no means of driving his fan or pump other than by hand power, and more than a century elapsed before his ideas were applied in practice.

Centrifugal pumps were in the past accepted by engineers as suitable appliances for easily and cheaply (as to first cost) raising water to low heads. It was not realized that they were capable of dealing with any but such heads; in fact, such a view became a canon of ordinary engineering practice, creating a tradition which took many years to remove. That this opinion was not universal is shown at a very early date by the omnibus patent of John Gwynne.† Included in this invention is the design of a series centrifugal pump shown in Fig. 1.

Gwynne's specification contains many claims, and amongst other

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* Philosophical Transactions, Vol. XXIV, No. 300, 1705.

† Patent No. 13,577 of 1851.

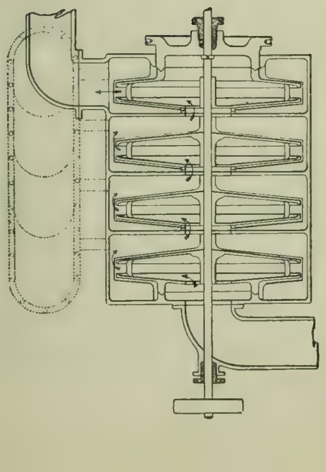

FIG. 1.—*Centrifugal Pump.* (John Gwynne, 1851.)

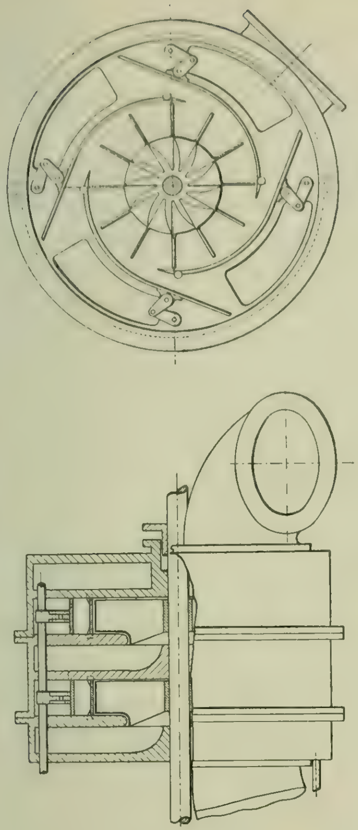

FIG. 2.—*Turbine-Pump.* (Osborne Reynolds, 1875.)

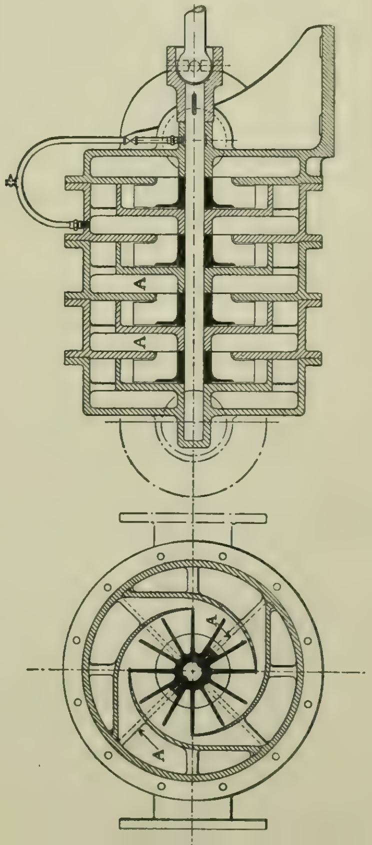

FIG. 3.—*Osborne Reynolds Pump*, 1887.

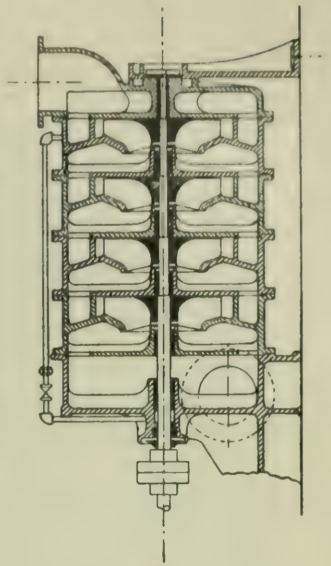

FIG. 5.—*Mather-Reynolds Pump*, 1895.

interesting designs he shows a reaction impeller, now used for self-regulation, and also a means of dealing with end-thrust. This specification seems to be the first proposal to use centrifugal impellers in series, and though in the forms shown and having no guide-vanes it could hardly be expected to attain even with low efficiency the heads now successfully dealt with, still it shows a conception of a machine very much in advance of the times. It is singular that, though the water-turbine with its guide-vanes was a matter of common knowledge at the time, no attempt appears to have been made to reverse its action with the prospect of obtaining a similar high efficiency and increase of head, for the purpose of raising water. There was however one exception, in the invention of Professor Osborne Reynolds. It is the object of the present Paper to trace and discuss the development of this invention.

In the year 1875 Professor Osborne Reynolds invented a turbine-pump * of the series type, fitted with guide-vanes, Fig. 2 (page 9). Comparison of this figure with illustrations following show how the essential features of his original proposition have been adopted in subsequent practice. In this pump the impeller delivered its water to tangent guide-vanes, as shown in Fig. 2,† and the similarity to an inward-flow turbine of the Thomson type is noticeable, for, as in that machine, the mouths of the guide-channels could be regulated to raise the efficiency of the pump for smaller outputs, a device however seldom adopted in later practice. He claims "the arrangement and combination of two or more centrifugal pumps or fans, in which the fluid, after leaving the moving passages, is received into fixed passages, so formed as to deprive it of all velocity of whirl."

Nothing of any commercial value appears to have been done with the invention for many years; in fact, the first pump of which records and tests are available was only constructed in the year 1887 by the firm of Mather and Platt for the Engineering

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* Patent No. 724 of 1875.

† *See also* Patent Specification 13,578 of 1894. Osborne Reynolds, "Improvements in Rotary Pumps and Turbines."

Laboratory of the Owens College, Manchester. This pump, shown in cross and longitudinal section in Fig. 3, had four impellers in series and gave at 1,500 revolutions per minute a total head of 148 feet or 37 feet per chamber. The average efficiency recorded in the tests made by Professor Reynolds was 58·5 per cent., a high result, having regard to its small size, for a pump made twenty-five years ago. The readings were taken from a dynamometer fixed between the pump and the belt-pulley, and, as no method of damping the indicating finger seems to have been employed, they may be liable to some error. Thus the maximum efficiency obtained, namely, 70 per cent., appears open to some doubt. The guide-vanes, after leaving the wheel in a curve, reached the inner periphery of the outer shell of the chamber at an angle. The water having had its velocity of whirl converted into pressure-head in these passages, had then to pass sideways at right angles into radial return-passages formed in the back portion of the chamber and marked "A" in Fig. 3. In these passages the water was guided and prevented from rotating by radial vanes. The water on reaching the centre passed into the eye of the second impeller, and so on until it was finally delivered at the pump outlet at the head pressure required. It will be observed from Fig. 3 that the impeller was of the open type with radial vanes.

The tests of Professor Reynolds proved the capability of the pump to perform many duties, previously thought impossible by centrifugal pumps, and in 1893 the firm of Mather and Platt took up its commercial manufacture.

The mechanical construction of a standard Mather-Reynolds pump as built in 1895 is illustrated in longitudinal section in Fig. 5 (page 9) and in photo, Fig. 4, Plate 1. It consists of four chambers working in series. At the one end, these are secured by bolts against the circular flange of a frame carrying the driving pulley or shaft coupling, this having the suction branch and entrance to the first chamber cast with it. At the other end the delivery chamber forms the final cover, and has the delivery pipe cast on the upper part connecting to the annular space into which the last set of guide-passages deliver, and at this end a suitable stay is attached to support the pump from the floor. The chambers are secured to each other by bolts through external flanges, each chamber being recessed and spigoted so as to preserve correct alignment of the whole. This forms an inexpensive design, and permits of accurate manufacture. It allows of chambers being added or subtracted for higher or lower heads. Each chamber is distinct in itself, and has on one side the guide-vanes, receiving the discharge from the impeller, and on the other the return-passage to the eye of the next impeller. This return-passage is walled by a diaphragm integral with the casting. The water leaving the impeller, guided by the delivery vanes, passes to the next chamber and is there guided to the eye of the following impeller. As shown in photos, Fig. 4 and Fig. 8 (right-hand side), Plate 1, there are four guide-passages in this particular pump and their form is clearly illustrated.

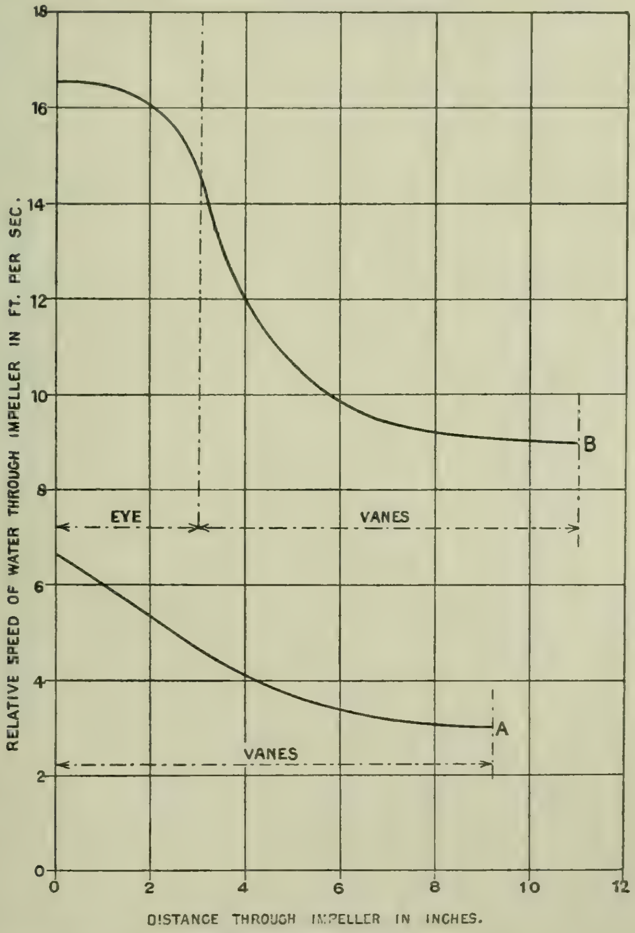
In comparing such a pump with a modern one, it will be found that it is in the form of its impeller and its delivery-casing that the original Mather-Reynolds pump differed most from the present design. The impeller as shown in photo, Fig. 4, Plate 1, is of the open type (not shrouded), with radial vanes, the roots of which are carried across the openings of the eye into the boss, necessitating the use of a modified form of Francis entrance. This form was probably adopted in order to secure sufficient strength to drive the vanes, necessitating them being carried through full width to the boss on the pump-shaft, and not starting level with the outer diameter of the eye as now. The impeller was turned all over, and revolved a close fit in its casing, which was turned to a corresponding form. This prevented leakage and loss of efficiency by the return of the water from the tip to the suction along the impeller sides.

The reasons that induced Professor Reynolds to adopt such a radial impeller are not quite clear, as the shrouded form with curved back blades was in common use at that time, and is a more efficient and stronger type. Recent experiments of Dr. Gibson and Mr. Ryan have shown that in centrifugal pumps with open-vane impellers the frictional resistance is three to five times as great as with closed or shrouded ones, though it must be noted that these experiments were made with clearances considerably greater than obtained with the Reynolds impeller.*

FIG. 6.

Curves showing relative velocity of water through impellers, when delivering their most efficient quantity.

A. Mather-Reynolds 1895 pump.
B. Modern High-Lift pump.



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* Proceedings, Inst. C.E., 1910, vol. clxxix, page 313.

In the 1895-pumps the speeds of the water through the impeller and passages were comparatively low, and large areas were therefore necessary, *see* Fig. 6. Each wheel being of the open type was nearly balanced as to end-thrust in itself, and so, with the moderate heads pumped against, troubles with lateral end-thrust were not experienced. There is no doubt, however, that end-thrust did occur, and this caused the impellers to rub on the sides of their casings with consequent friction, wear causing leakage and loss of efficiency, the varying conditions of which make the true comparison of various tests difficult. This, however, did not cause any serious trouble in practice on account of the large areas on which the end-thrust was taken, and the low-head per chamber.

FIG. 7.—*Head and Efficiency Curves.*
Comparison of Results with Different Impellers.

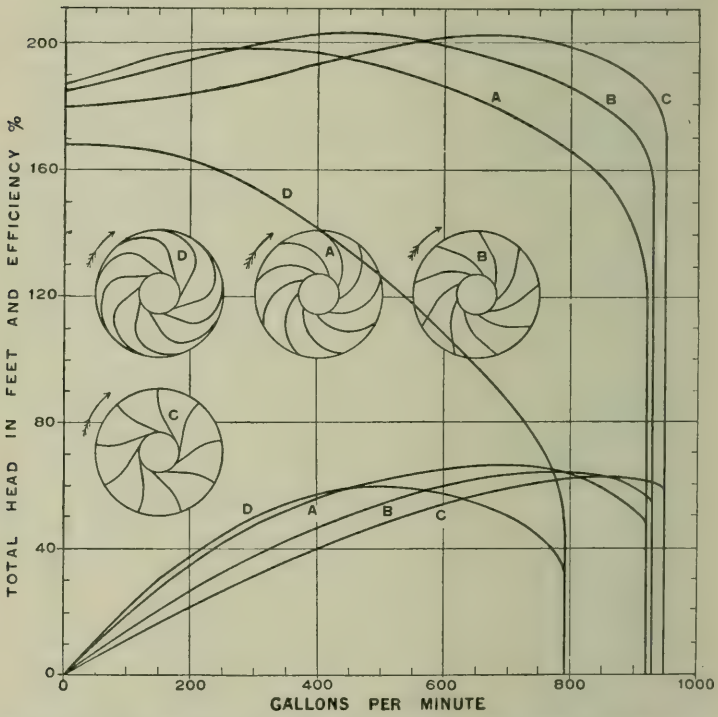

Fig. 7 shows curves taken on the works test-tanks from the impellers A, B, C, D, tested in the same single chamber pump body, and with one set of short guide-vanes. These impellers were not of the 1895 type but shrouded. The curves are given solely for the purpose of showing the effect of different forms of impeller-vanes working under similar conditions. They illustrate the advantage in efficiency of the impeller with the backward curved vanes,* and in head of the one with radial vanes. Impeller C most nearly corresponds to the radial vanes of Reynolds, and impeller A to the modern type. The reaction wheel D gives a gradually falling head curve as the quantity becomes abnormal, with smaller tendency to increase the driving power and lower efficiency. To obtain the best results of each impeller, different guide-passages with suitable entrance angles should have been used.

Considering now the guide-vanes, it will be seen that in the 1895-pump these are shorter, or rather open out quicker than in a modern pump, *see* photo Fig. 8, Plate 1. They are obviously less efficient if judged from the analogy of a Venturi tube, which must have a certain (long) length if serious loss is not to be occasioned by converting velocity into pressure. The difference, therefore, between the efficiency of an 1895-pump and modern pump, as shown in curves, Fig. 9 (page 16), is probably due to the form of the Reynolds impeller and its guides with its cramped entrance at the eye with consequent shock to the entering water, and to the loss at the periphery from the radial vanes, also to the shortness or too rapid opening out of the guides. The importance of long and carefully formed divergent guide-channels is shown by curves, Fig. 10, and photo Fig. 11, Plate 2, the same impeller being used in each case. Fig. 11 shows photos of the short and long guide-passages.

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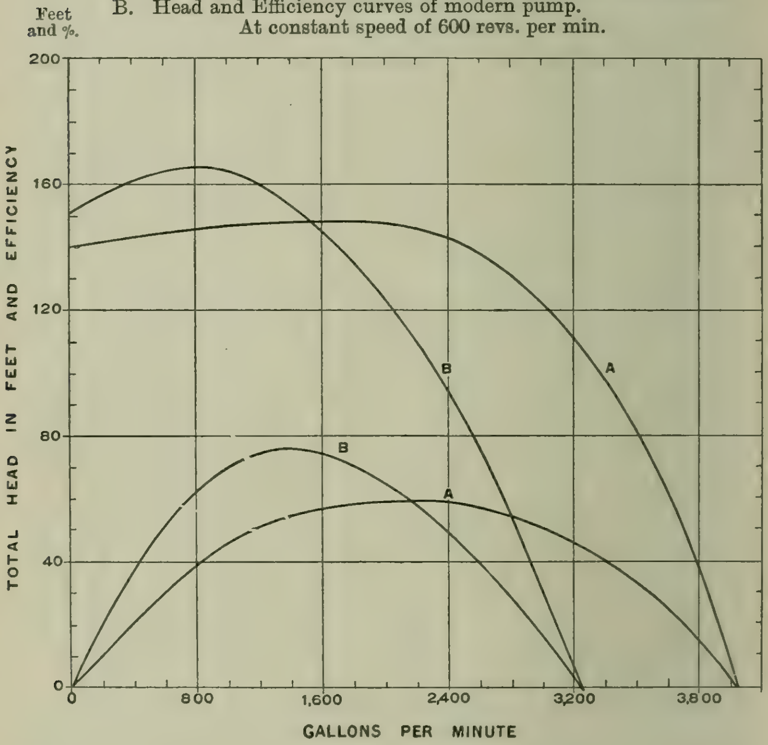
* For a discussion of the superior efficiency of curved vanes over radial vanes, *see* Dr. Stanton's Paper on "Centrifugal Pump Efficiency," Proceedings Inst. Mech. E., 1903, page 715.

NOTE.—The authors are informed that in some tests on the efficiency of pumps, the kinetic energy of the water as delivered from the pumps is added to the energy as measured by the product of the head (measured by gauges fixed at the same level on the delivery and suction) and the quantity in determining the work done by the pump. This is obviously incorrect, unless the kinetic energy of the water entering at the suction side is deducted from the work done by the pump. As in general the velocity of inflow and outflow is the same, the two factors balance each other, and the work done is truly represented by the product of the quantity and the head.

FIG. 9.

A. Head and Efficiency curves of Mather-Reynolds 1895-pump.
B. Head and Efficiency curves of modern pump.
At constant speed of 600 revs. per min.

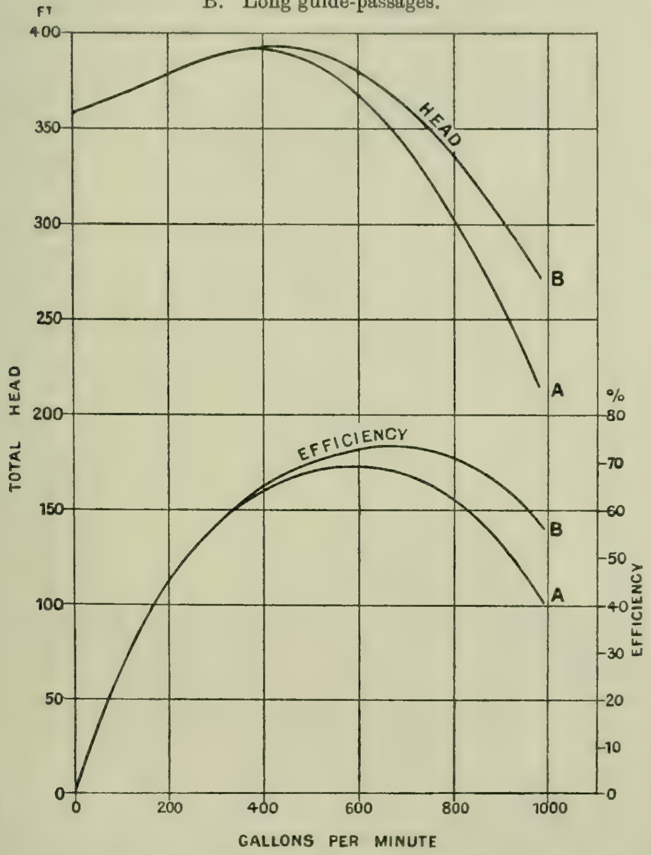


The effect of the curvature, length and dimensions of entrance of the guide-passages and of the curvature and angle of delivery of the return-passages on to the eye of the impeller are shown in curves, Fig. 12 (page 18). These curves have no relation to the curves of Fig. 7, being taken at an earlier date with a different pump.

Head and efficiency curves are given for four different designs of guide and return passages, the same impeller of standard shrouded type being used in each case. Design A has short guide-vanes with wide opening on the radial line. The return-passages are of similar curvature. Design B has similar guide-vanes, but the return-passages have a short curve becoming radial near the eye of the impeller. Design C also has similar guide-vanes and the return-passages are similar in curvature to those of A, but are not extended

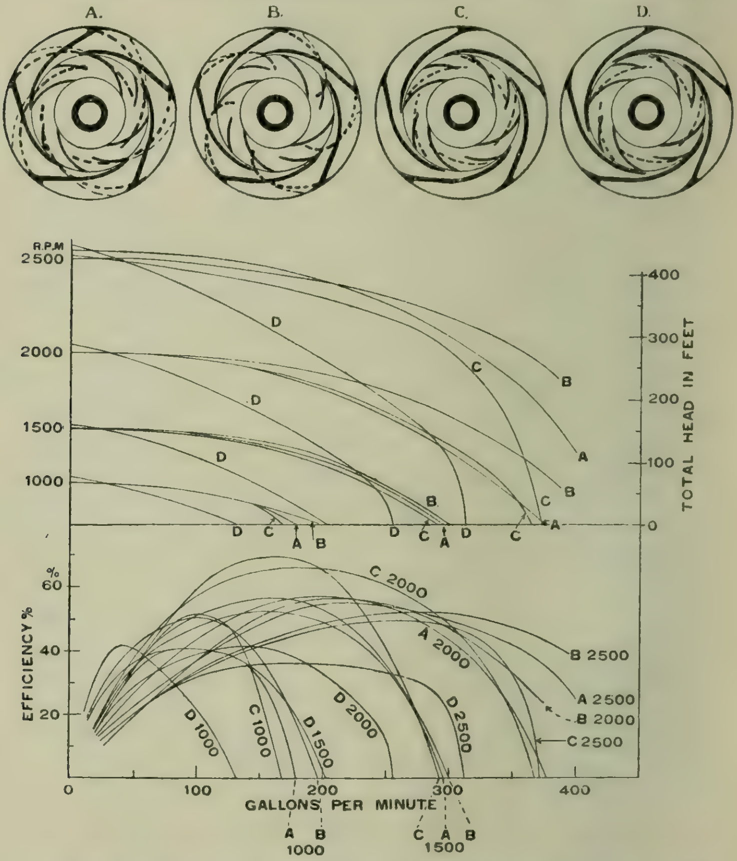
FIG. 10.—*Head and Efficiency Curves.*

A. Short guide-passages.
B. Long guide-passages.



to the outer periphery of the return chamber. Design D has a narrower opening on the radial line, one-half that in A, B and C. The return-passages are similar to C.

FIG. 12.—*Head and Efficiency Curves.*
Showing effect of Guide-passages and Return-passages of different Form.



The head and efficiency curves are given for speeds of 1,000, 1,500, 2,000 and 2,500 revolutions per minute respectively. An inspection of the curves shows that design D is much inferior both in head generated and in efficiency, due to the throttling at the throat of the guide-passages, and incidentally that self-regulation

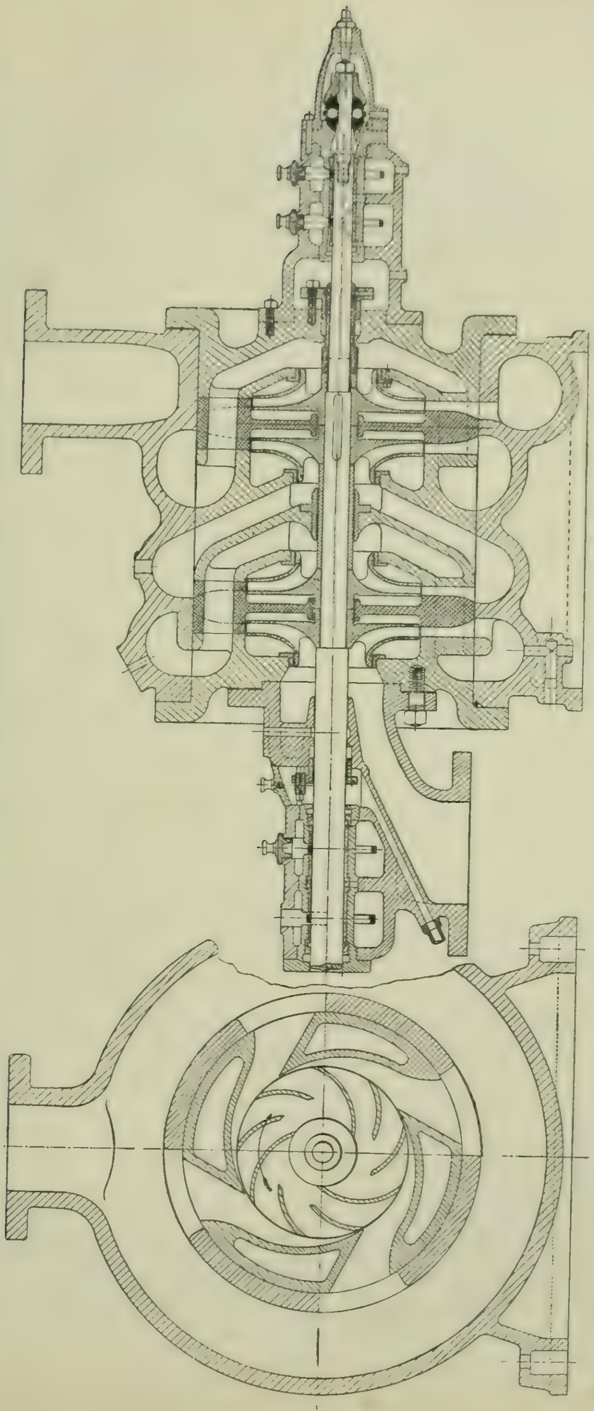
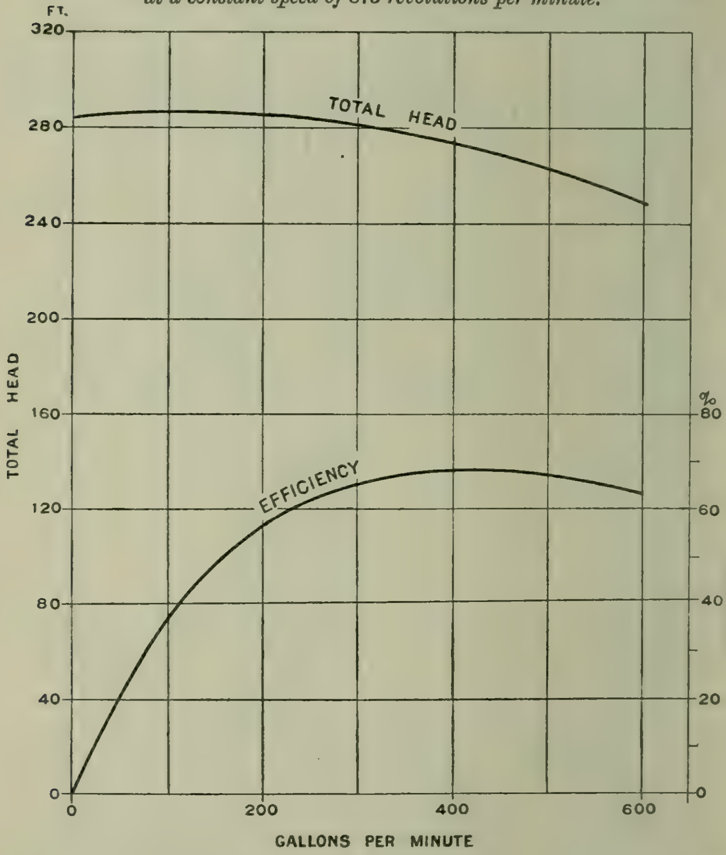


FIG. 13.
Four-Chamber High-Lift Centrifugal Pump. (Sulzer Brothers.)

may be readily attained by such throttling, as it may also be obtained by throttling at the eye or less effectively by a reaction form of impeller, as shown in curves, Fig. 7. Secondly, that design B is superior to both A and C in generation of head especially with larger quantities, and superior to A in efficiency especially at the low speeds, but it is much inferior to C in maximum efficiency except at the high speeds. At these speeds eddying and whirling take place in the whirlpool chamber of C, which is prevented by the

FIG. 14.—*Test of Four-Chamber Turbine-Pump* (Sulzer) *when running at a constant speed of* 875 *revolutions per minute.*



guides forming the continuous passages of design B. Design B is most usually adopted as best meeting average conditions.

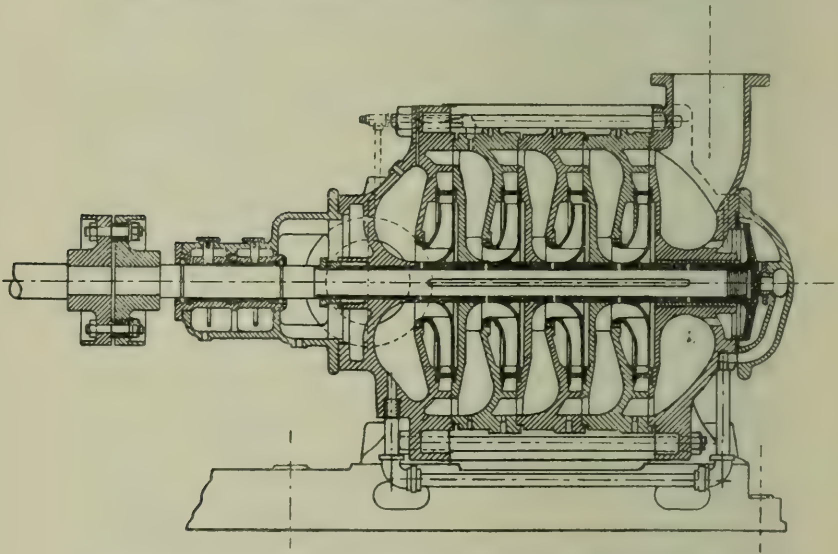
Thirdly, that design C, which approaches more nearly to the conditions of a single-chamber pump, gives considerably higher maximum efficiency at speeds of 1,500 and 2,000, due to less power being absorbed by friction against the walls of the guide-passages, and also to tangential motion imparted to the water as it enters the subsequent impeller by the tangential curvature of the return passages.

A considerable number of pumps of the 1895 form were constructed for installations in this country and abroad, some of which are described later. Meanwhile Messrs. Sulzer Bros., of Winterthur, had commenced the manufacture of multiple turbine pumps about the year 1896, and had evolved various modifications in the Osborne Reynolds design, whereby both the efficiency and the lifting capacity were considerably improved. They had established in 1898 an interesting and novel installation of these improved pumps at the Spanish mines of Horcajo, which attracted considerable attention. (*See* page 25.) Two years later an agreement was concluded between Messrs. Sulzer Bros. and Messrs. Mather and Platt providing for an interchange of future improvements and due acknowledgment of the original work of Professor Osborne Reynolds and of the improvements made by the two manufacturing firms.

A four-chamber pump of the Sulzer design is shown in longitudinal and cross sections in Fig. 13 (page 19). Comparing this with the 1895 design, three important differences are noticeable. Firstly, the body casting of the pump is constructed in one piece, with the intermediate pieces, guide-vanes, and impellers put in from one end. Secondly, the impellers are shrouded and have backward-curved vanes. Thirdly, the impellers are arranged back to back to compensate for the increased lateral end-pressure set up by the higher heads worked against. This arrangement of the impellers involved the use of somewhat tortuous passages in the pump to bring the discharge of the first impeller to the eye of the second, and so on. Moreover, these passages passing several joints increased the probability of internal leakage from one stage to another. Curves of head and efficiency of such a pump are shown in Fig. 14 (page 20).

The agreement between Sulzer Bros. and Mather and Platt came to an end by mutual consent in 1904, and after that date each firm further developed their pumps on their own lines. The authors deal now only with the improvements of Mather and Platt, not having knowledge of Messrs. Sulzer's work beyond what is generally available through publication.

FIG. 15.—*Modern Four-Chamber Pump.* (Mather and Platt.)



Proceeding now to the discussion of later designs, a four-chamber pump is shown in longitudinal section in Fig. 15, its guide-vanes in photo Fig. 8, Plate 1 (left-hand side), and its impeller in photo Fig. 16, Plate 2. It will be seen that constructionally this pump differs principally in that the extended suction-end is shortened, and is similar to the delivery-end. This enables various classes of drives, motor, belt, or steam-turbine, to be better negotiated with a standard pattern. Successive chambers, instead of being secured to their neighbours by bolts and flanges, are held together by long bolts extending the entire length of the pump body and held only at the two ends (suction and delivery). This construction secures amongst other things some economy in manufacture.

The impeller is of the shrouded type, having vanes bent well backwards and the guide-passages are longer and more correctly divergent, whilst the return-way to the eye of the next impeller is of a curved form and more in line and continuous with the receptive ports, thus preventing the abrupt right-angle turn through the casing obtaining in the Reynolds pump. The losses in the Reynolds impeller through side friction in its casing are obviated, and any leakage from the periphery back to the suction is prevented or greatly minimized by the outer circumference of the impeller eye running in neck bushes with a very small radial clearance, amounting to less than 0·005 inch. The importance of preventing this leakage is very great if high efficiency is to be secured. The impeller is turned all over outside to reduce loss by skin friction,* and with the same object it is usual to use as many wheels as the circumstances will otherwise allow of.

The end or axial balance of the impellers is obtained by the automatic device shown, which acts well in practice, and compensates for wear and variable leakage taking place in the pump. In other respects the arrangement, direction of flow of water, and assemblage of the pump are the same as in the original Mather-Reynolds pump.

Representative curves of head and efficiency of such a pump are shown in Fig. 9 (page 16).

INSTALLATIONS.

Bore-hole Pump. 1897.—This pump installation is particularly interesting on account of its novelty. The pump consists of six chambers in series and is arranged to work suspended in a bore-hole at a depth of 100 feet below the surface; it has a capacity of 850 gallons per minute, with a lift of 170 feet and runs at 1,000 revolutions per minute.

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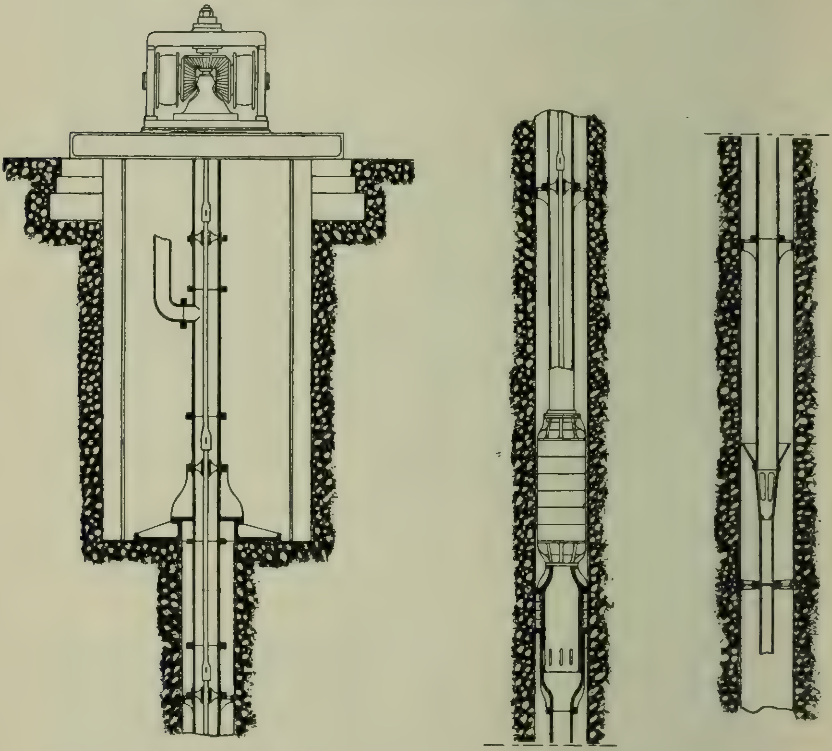
* For a discussion of this skin friction, *see* Paper by Gibson and Ryan cited on page 13.

The general arrangement of the rising main by which the pump is suspended is shown in Fig. 17. The pump and main rest on a crutch pipe at the bottom of the bore-hole. The pump is specially designed to fit the bore-hole lining tube, and its overall diameter is necessarily reduced. It is driven by a vertical shaft passing down the centre of the rising main and supported at each pipe-joint by suitable stay bearings. At the surface this shaft is arranged with double bevel-gears and pulleys driven from a steam-engine.

FIG. 17.

Arrangement of Mather-Reynolds Pump in Bore-hole, 1897.



An interesting feature of this installation is shown in the illustration immediately below the pump, consisting of an expanding plug which effectively stops out all objectionable surface water, allowing the supply desired to come in through the suction pipe suspended below. This pump has given continuous service for over fourteen years, during which time it has received no repairs. In fact it has only once been brought to the surface during this period, when a portion of the shaft in the bore-hole was found to be corroded and required renewal.

Mine Pumps: Sulzer Installation of 1898.—The authors believe this to be the first installation of centrifugal turbine-pumps of large capacity for mine drainage. It consisted of three multiple pumps arranged in stages, the pump of each stage delivering direct through the rising main to the stage above. The pumps were motor-driven and each set was erected in a chamber off-set from the mine-shaft measuring 26 feet by 11 feet 6 inches by 11 feet 6 inches, thus demonstrating the great convenience afforded by this type of pump for underground work. The capacity of the installation was 1,000 gallons per minute against a total head of 1,500 feet.

Engineering Laboratory Plant. 1900.—This plant, constructed for the Engineering Laboratory of the University of Cambridge, consisted of a pump at one end, a similar turbine at the other end, and an electric motor between them. It forms an interesting combination designed for the purpose of carrying out a variety of tests. It could be worked either as a motor-driven pump, or a turbine-driven dynamo or as a combination, the motor making up the loss of power in the water passing the turbine and pump, thus giving a hydraulic Hopkinson-test. For this last purpose the magnets of the motor were slung on ball-bearings and provided with arrangements for measuring the torque.

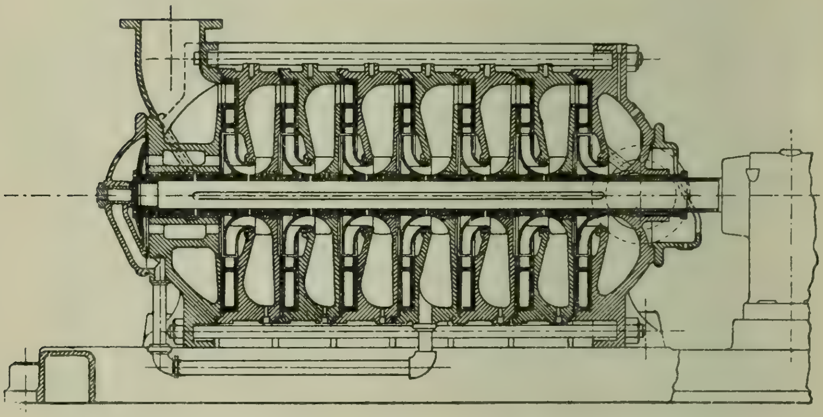
Newcastle Electric Power Station. 1901.—The combination above described was made use of later for actual installations, amongst others at the Newcastle Electric Power Station for circulating the condensing water. The pump raised and forced water from the river to the condenser in the electric generating station in the town, the return flow to the river passing through and driving the turbine, the loss being made up by the electric motor in between.*

Mine-Drainage Pump. 1911.—Fig. 18 and photo, Fig. 19, Plate 2, shows a section through a series turbine-pump lately constructed for mine drainage. It is interesting, as it is probably the mine pump with the largest capacity yet constructed. This pump is capable of delivering 2,500 gallons per minute to a height of 2,000 feet when running at a speed of 1,450 revolutions per minute, and absorbs over 1,900 h.p. at the spindle. It is operated by a three-phase motor of 2,500 volts, direct coupled through a flexible coupling of the pin and rubber-bush type.

FIG. 18.

Mine-Drainage Pump, 1911.

(Mather and Platt.)



The pump has seven impellers arranged in series working in chambers, following each other in the same manner as those pumps already described, and not as is sometimes done for such high heads by arranging the impellers back to back, with the intention thus to balance the end-pressure. The series impellers are constructed of phosphor-bronze, and are mounted on a shaft of extra large diameter, to prevent sag in the middle and allow of fine clearance in the neck rings at the eyes of the impellers, thus reducing leakage. The guide-vanes into which the impellers discharge are large castings of special bronze, double-sided and cast in one piece, thus securing increased rigidity.

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* Paper by C. Hopkinson on "Pumping Plant for Condensing Water," Proceedings, Inst. Mech. E., 1902, Part 3, page 437.

The intermediate chambers have the return-passages from the periphery to the suction of the next impeller cast in. They are of cast-iron, and have feet cast on, which, resting on the planed surface of the bedplate, support and keep the whole pump in true alignment, a precaution more necessary when the length of the pump is as great as in this case. The construction also facilitates the stripping and rebuilding of large pumps. There is only one exterior bearing, in the form of a separate pedestal standing on and bolted to the main bedplate at the suction end. The reason for this bearing being separate and of such a solid form and not overhung from the pump-casing, as in the more standard form of smaller pumps, is due to the large power transmitted through the pump-shaft at a high speed. There is a water-logging passage to the shaft at the suction stuffing-box to prevent air leakage.

At the delivery end of the pump there is an internal automatically grease-lubricated bearing and a differential end balance-plate readily accessible for examination and adjustment, a great advantage with dirty waters. This construction obviates the disadvantages of a gland at the delivery end, subject to the full head pressure, with its attendant leakage and cutting of shaft. The lubrication of the internal bearings is effected by a piston worked by the head pressure pumped against.

Boiler Feed-Pump. 1909.—Photos Figs. 20 and 21, Plate 3, show an electrically-driven boiler feed-pump, consisting of two six-chamber pumps in series, of the split-body type, allowing of the whole of the inside impellers, shaft and guides being taken out together when the top half-cover is removed. This is a much simpler and quicker

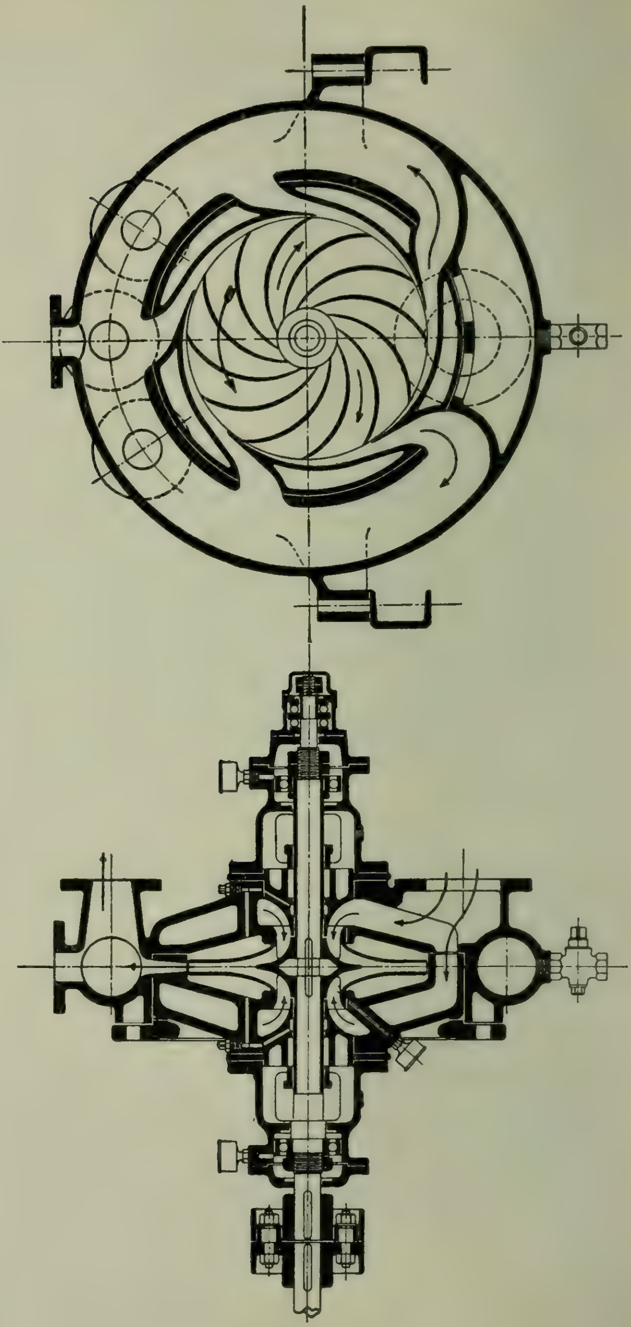


FIG. 22.—*Single-Chamber High-Lift Turbine-Pump.*
(Mather and Platt.)

operation than taking adrift a standard type, but it is a more expensive form of construction.

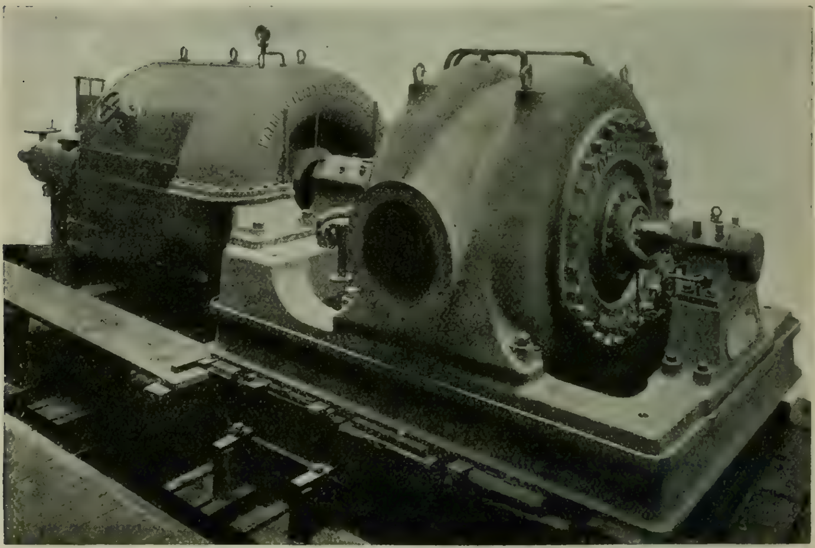
The difficulty in such a design is to deal with the internal water-pressure of 260 lb. per square inch on the split joint. Reference to the illustration will show how this is accomplished. It will be seen that the impellers are surrounded by guide-plates, put on in halves and bolted together, and the whole is then placed in a casing divided in the middle horizontal plane. The casing is provided with as many dividing ribs as there are impellers. Turned bosses on the guide-disks rest in suitably machined seats in the dividing ribs. The top cover is bolted on to secure them in their places, and they are prevented from rotating by pins. The main joint against heavy pressures is thus a plain one and of great rigidity, and can easily be maintained tight. The capacity of the pump shown in photos, Plate 3, is 140 gallons per minute, 260 lb. per square inch delivery pressure at 1,270 revolutions per minute.

Fire-Pumps.—An interesting application of the turbine-pump for fire-prevention purposes, as fitted to petrol automobile fire-engines, is shown in Fig. 22. The capacity varies usually from 350 to 1,000 gallons per minute, against a head of 250 to 300 feet. The pump has a single chamber and is designed to fit on the back part of the chassis of an automobile, and to be driven by an extended shaft from the engine. The regularity of the flow of water delivered renders the holding of the hose-jets much easier and the action of the turbine-pump allows the shutting off of any particular jet, or of all the jets, without any tendency to burst the hose-pipes, as may be the case with a reciprocating pump. Further, the pump is much lighter than a corresponding pump of reciprocating type, and takes up considerably less space. The difficulties incident to starting with a heavy suction can be met by the provision of a small auxiliary pump which exhausts the suction-pipe, thus causing the water to fill the turbine-pump. As soon as the turbine-pump has developed its head pressure, the auxiliary pump can be put out of action, and the turbine-pump will continue to work with suction lifts up to at least 80 per cent. of the height of the barometric water column.

Waterworks Pump driven direct by a Steam-Turbine. 1908.—This pump, like the mine-drainage pump, already described, is of very large capacity, but differs from it in running at a high speed, being driven direct by a steam-turbine. The plant is installed at the St. Gabriel Pumping Station of the Montreal Water and Power Co., situated on the banks of the St. Lawrence, and is capable of delivering in continuous work 10,500 gallons per minute at a head of 404 feet. The turbine is of the Zoelly type, 1,350 to 1,500 revolutions per minute, and is capable of normally developing 1,720 b.h.p. with steam at 165 lb. per square inch and 150° F. superheat. The air-pump of the condenser is independently driven through reduction gear by an enclosed high-speed reciprocating

FIG. 23.

Waterworks Pump driven by a Steam-Turbine. 1908.



engine placed at a lower level than the steam-turbine pump. This auxiliary engine is of about 275 h.p. and runs at 465 revolutions per minute. Direct coupled to the other end of the shaft is an auxiliary low-lift pump which draws water from the suction-well and delivers it to the main pump at a small pressure, thus relieving the main pump from suction, and thereby effectively preventing any trouble in that pump from cavitation. A portion of the water from the auxiliary pump is by-passed through the condenser on its way to the main pump. It thus serves also as a circulating pump. The main pump is of special design in that, owing to the high speed, only one impeller is needed to give the head and two are required for 'the quantity. Consequently the pump is of two-chambered parallel type. Each of the impellers has a double entrance, so that the shaft is in lateral equilibrium and no balancing device is required. A plant of this character has great advantage over a direct-acting or gear-driven reciprocating-pump in the relative smallness of the space occupied and foundations required and in silency of operation. The steam-turbine and pump are illustrated in photo, Fig. 23. This pump and the mine-drainage pump, already described, so far as the authors are aware, are the largest of their type in the world, and so give a fitting indication of the development of the Reynolds turbine-pump since its inception thirty-seven years ago, and illustrate some of its great possibilities in various duties.

The Paper is illustrated by Plates 1–3 and 16 Figs. in the letterpress.

Discussion.

The PRESIDENT said that, from the applause, it was evidently quite unnecessary to ask the members to accord the authors a hearty vote of thanks for the very interesting account they had given of the great development in turbine machinery, but nevertheless he would formally put the motion.

The motion was carried.

Dr. EDWARD HOPKINSON wished to take the opportunity of making one or two remarks which were not immediately germane to the Paper. In writing it, the authors had desired to confine themselves strictly to the turbine-pump, and not to wander into by-ways which naturally suggested themselves and which would have been interesting to follow. It would have been of considerable interest, for instance, to compare the advantages and disadvantages of the turbine-pump and other forms of pumps, but they had deliberately avoided doing so, and he hoped that the discussion which followed would be confined chiefly to turbine-pumps. The authors had also been deprived of what would have been a pleasure to both of them, namely, making reference to some of the earlier work which related more particularly, not to the turbine-pump, but to the centrifugal pump, taking the general acceptance of the term. The history of the centrifugal pump was one of singular interest and well worth study. After the quite early work of Papin, to which reference had been made in the Paper, very little progress seemed to have been made in the development of centrifugal pumps until about the year 1851, when Mr. Gwynne brought out his invention, and, at the same time, Mr. John Appold showed a pump at the great Exhibition of that year, in which he, it was believed for the first time, made use of impellers with back-curved vanes, and obtained, according to his own statement, an efficiency three times greater than anything obtained before. It was not known, he believed, what efficiency was actually obtained, but if it was three times greater than that obtained before, the centrifugal pump must previously have been in a very elementary stage of development. After the year 1851 there was again a long gap until Professor Reynolds' work, and that, like much of Professor Reynolds' work, was pigeon-holed and quite unknown generally.

The design of centrifugal pumps was first brought prominently before engineers by the Hon. R. C. Parsons in a Paper written about the year 1876, when he was a student and an apprentice of Messrs. Easton and Anderson. As a Student of the Institution of Civil Engineers, Mr. Parsons presented a Paper* to that Institution, which had the honour of being selected to be printed in the Proceedings and was awarded the Miller Prize. In that Paper Mr. Parsons made the first careful and satisfactory experiments on the efficiency of pumps. The pumps were quite small, with a duty of only about 7 feet lift and 1,000 gallons per minute, but still in that Paper the foundations were laid for much subsequent work.

After 1876, the next point which the authors would have liked to record, but found it to be outside the scope of the Paper, was the work of one of the Vice-Presidents of the Institution, Dr. Unwin. He believed it was in the year 1877 that Dr. Unwin took up the Paper by Mr. Parsons and worked out theoretically the complete equations of the efficiency of the centrifugal pump and applied them to the work of Mr. Parsons, and proved at the same time the accuracy of that work and the accuracy of his own equations. As far as he recollected, that Paper did not deal with the question of guide-vanes, which was the distinctive feature of the turbine-pump; it simply mentioned them and passed them by as being impracticable and useless.

One other point he might mention in the history of pumps, which was of interest as being closely connected with the Institution, was a Paper, by Dr. Stanton in the year 1903. That also was a classical Paper marking a great stage in the advance of centrifugal pumps, and in that Paper, amongst other things, the effect of guide-vanes was very fully discussed. After that the development of the centrifugal pump passed into the hands of many manufacturing

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* Proceedings, Inst. C.E., 1877, vol. xlvii, page 267.

(Dr. Edward Hopkinson.)

firms in this country and abroad, and they had developed each on their own lines. Naturally Mr. Chorlton and himself did not think it suitable to refer to the work of other manufacturers in particular, although it would have been interesting to do so. They hoped, however, that manufacturing firms who might be represented that evening would refer to those developments more adequately than the authors could do.

Dr. W. CAWTHORNE UNWIN (Member of Council) said that the Institution ought to be very much obliged to the authors for the Paper they had read. It gave a complete account and an exceedingly clear explanation of a very remarkable recent development in pumping, and it covered the whole ground so completely that there was very little else to say which was not rather of a historical nature. He noticed that on page 8 the authors said "Centrifugal pumps were in the past accepted by engineers as suitable appliances for easily and cheaply (as to first cost) raising water to low heads." Probably that statement was true, but it was known to a few engineers even at a comparatively early time that, if properly constructed, centrifugal pumps were not only cheap but were efficient; in fact they were the most efficient pumping machines, if properly constructed, on low heads.

The authors had mentioned what was probably the earliest proposal for the application of pumps in series, and had given a sketch in Fig. 1 (page 9) of the series pump of 1851. In 1863 General Morin published a work on machines for lifting water in which the Gwynne pump was described, and also a pump which was somewhat less crude, designed by the well-known French engineer, Girard. That showed that series pumps were thought of at a comparatively early time. Why they made no progress, he thought, was due to the fact that the earlier builders of centrifugal pumps—and he himself made no difference between the centrifugal pump and the turbine pump—were not well acquainted with the means of utilizing in any way the large amount of kinetic energy corresponding to the tangential velocity of the water when it left the pump-disk. If they had known a little more about that, he thought the series pump might have come into use at an earlier period.

It would be well known to all the members that pumps and motors were simply reciprocal machines. The hydraulic turbine reversed was a turbine-pump; the reciprocating pump reversed was a hydraulic piston-motor, and so on. Looking at Fig. 2 (page 9), not to the longitudinal section which showed a series of pumps, but to the view of the cross-section of the pump, that was absolutely and identically a Thomson vortex turbine, a turbine with movable guide-blades, such as he himself had made during the "Sixties," generally under the design and patent of Professor James Thomson. Most of those turbines were made with curved vanes, but some were made with straight vanes, as shown in the Fig. To make clear exactly what Professor Osborne Reynolds did, he might explain that Professor Reynolds knew perfectly well of the vortex turbine. He took a vortex turbine of Professor Thomson's and reversed it and put it in series. That put his case, he thought, exactly. The reversed turbine was a turbine-pump, but there was a difference in the general action of a hydraulic turbine of that kind and a hydraulic pump. In the case of the hydraulic inward-flow turbine, broadly speaking, the water was flowing constantly through narrowing passages, and in that case the motion of the water was comparatively stable. If it was reversed then, broadly speaking, the water was flowing through expanding passages and there was much less stability in the motion of the water and much greater liability to loss through eddying motions. That was the reason people had not realized why so very large a number of centrifugal pumps, that had been made by makers of no particular insight, had had such very low efficiencies.

One of the largest sources of loss in a great many centrifugal pumps was the loss of the kinetic energy of discharge. There were several ways in which the loss due to the kinetic energy of the water at the points where it was discharged from the pump-disk could be reduced, or at any rate there were two or three ways. It was reduced in the Appold pump by re-curving the vanes, because that reduced the tangential velocity of outflow. In various pumps

(Dr. W. Cawthorne Unwin.)

some guide-vanes had been used from fairly early times, but not to any very large extent. In guide-passages, such as those of the turbine-pump, the kinetic energy of discharge was largely converted into pressure and increased the lift. Professor James Thomson formed the idea of utilizing the action in what he called a whirlpool-chamber, and during the "Sixties" a number of pumps were made in which that chamber was a feature. Re-curved vanes were used as in the Appold pump, so that the tangential velocity was reduced, and a portion of the kinetic energy corresponding to the tangential velocity was changed into pressure by the use of a whirlpool-chamber.

He would like to mention that probably the largest centrifugal pump ever constructed was made under Professor James Thomson's direction. He (Dr. Unwin) superintended the construction of a pump for Demerara for pumping, on a very low lift of about 4 feet, water from marshes into the sea. The pump-disk was 16 feet in diameter and the whirlpool-chamber 32 feet in diameter. They assumed in those days that that pump could be constructed with an efficiency of 70 per cent. He did not think any exact experiments were made, but he thought an efficiency of that kind must have been very closely reached. It was driven by what in those days was also quite a new invention, one of the earliest Corliss engines made in this country. The engine was calculated to work to such a power as would drive the pump, on the assumption that it had an efficiency of 70 per cent. Really, with the exception of placing the pumps in series, he believed the Thomson pumps were pretty nearly as much turbine-pumps as the pumps made later on, only nobody seemed, until Professor Osborne Reynolds took it up, to have made sufficient trials to show the advantage of placing pumps in series. He would like to know whether the velocities shown in Fig. 6 (page 13) were the velocities relative to the solid surfaces, as it was not quite clear. One important point required to be known about the pumps was not the relative velocity but the radial velocity of flow through the pump and its chambers, as the radial velocity was rather an important factor in the general design of the pumps.

Mr. W. E. W. MILLINGTON agreed with Dr. Unwin that he could not see any difference between a turbine-pump and a centrifugal pump; he could not see why adding guide-passages to a pump made it into a turbine-pump. In his opinion it was practically a trade name. The Paper had shown very clearly what rapid development had taken place in connection with centrifugal pumps, but nothing had been said as to why that development had taken place. One of the chief reasons was the small space which they occupied, a fact which of course made them very suitable for mining work; and the other was the low first-cost. Some little time ago he collected a few figures in connection with the initial cost, comparing them with costs of reciprocating pumps, and the following Table would give those figures:—

Gallons per Minute.	Head in Feet.	Centrifugal Pump and Motor.		Reciprocating Pump and Motor.	
		Horse-power.	Price.	Horse-power.	Price.
			£		£
167	750	60	280	55	510
300	400	52	180	55	480
300	100	14	110	20	310
700	607	190	390	180	1,640

The figures were of interest in showing the difference in the cost of some centrifugal pumps with motors and reciprocating pumps with motors for different outputs. After reading the Paper, he was almost led to think that the great striving during the last years in connection with centrifugal pumps had been after high efficiency. He did not think that was really so. The chief point was the attainment of high reliability. The question of reliability had been very much before the centrifugal-pump makers, because unless the centrifugal pump could be made very reliable it was quite certain that no colliery manager, for instance, would install

(Mr. W. E. W. Millington.)

such a pump, no matter how much he might be tempted by high efficiency.

In attaining reliability, one of the greatest difficulties had been the balancing of the end-thrust on the impellers. Many devices were used for that, and, until comparatively recently, in every case some balancing device was utilized, in which the end-thrust on the impellers was taken up as nearly as possible by some hydraulic means, and the remaining unbalanced load was taken up on the mechanical thrust-bearing. The only good solution was the automatic hydraulic balancing of the end-thrust, and he was sorry that so little was said about that matter in the Paper. It might be of interest, therefore, if he exhibited two slides showing such arrangements.

Balancing Arrangements in use on Centrifugal Pumps.

FIG. 24.

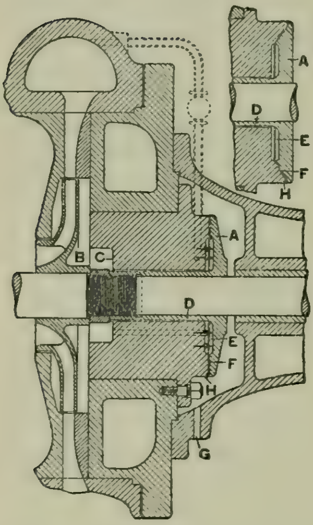


FIG. 25. (*See also* Fig. 26.)

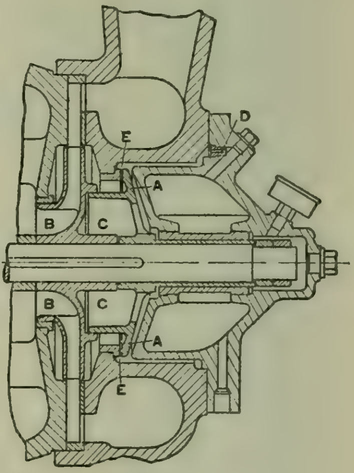


Fig. 24 showed a balancing arrangement used on the present-day Sulzer pumps, in which the impellers were not placed back to back as in the type illustrated in the Paper. The disk A was used for taking up the unbalanced load on the impellers. Water was allowed to escape from the periphery of the last impeller past B and C, and through the small clearance between the sleeve D and the body part C into the space E. It then passed through the space F away to the outside of the disk and through the opening G. If the unbalanced thrust was from right to left, then, the impellers and disk A being free to move axially, the result was that the face of the balance-disk A came closer to the face of the body H and less water was allowed to escape out of the chamber E; consequently the pressure was backed up in this chamber and gradually brought the impellers back to their proper position. The reverse action took place if the unbalanced thrust was from left to right. That was really an automatic hydraulic balancing. This design had disadvantages, as the balancing water had to pass through the small running clearance, and of course, as that wore, naturally more water passed and more water was required to balance the pump.

Fig. 25 showed another method of balancing. A disk was not employed in that case but a valve, marked A. Water was allowed to escape from the periphery of the last impeller B, past the valve-face into the chamber C, to the back of the impeller, and the thrust was taken up on the impeller itself, not on a disk. From the chamber C the water escaped through the orifice D away to a drain. The operation of automatic balancing was similar to that previously described. There was no chance of the orifice D becoming choked up, because when the pump was running the space E between the balance-valve and the face of the body was only about two-thousands of an inch, so that anything which went past that would certainly go through the orifice D. It was independent of wear, because, with the exception of the valve-face, there was no running clearance as in the last case.

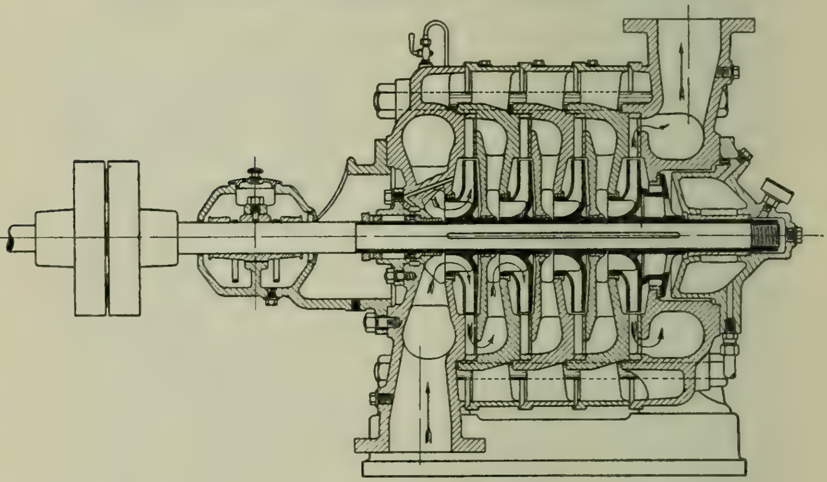
Fig. 26 (page 40) showed a section through a pump employing the latter type of balancing, and incidentally showed an internal delivery end-bearing along which no water could escape. It was somewhat different from those shown in the Paper. At the right-hand end grease was forced through the bearing into the balance-water

(Mr. W. E. W. Millington.)

chamber, and there was no tendency for water with any grit to get along the bearing at all. It would be noticed that the whole could be easily dismantled; the end-bearing could be taken away without disturbing the balance-valve, and the balance-valve itself could then be taken off without disturbing any other part of the pump.

The authors appeared to claim that the design D (page 18) was a good one for obtaining self-regulation, but if the curves were looked at, it would be found that the highest efficiency there was 40 per cent. Figs. 27 and 28 showed some curves he had taken off a pump of about the same output as the one illustrated in the Paper. Fig. 27 showed the curves of a pump arranged to give self-regulation, and Fig. 28 showed the same pump arranged as a standard pump without self-regulation. The authors took it for granted that everyone knew what self-regulation was, namely, that, after passing the maximum efficiency point, the power curve either remained flat or fell slightly, and in the case shown it would be noticed it actually fell. It would be seen there was an efficiency of about 63 per cent. obtained from a pump of about the same output as the one illustrated in the Paper.

FIG. 26.—*Four-stage Centrifugal Pump.* (Holden and Brooke.)

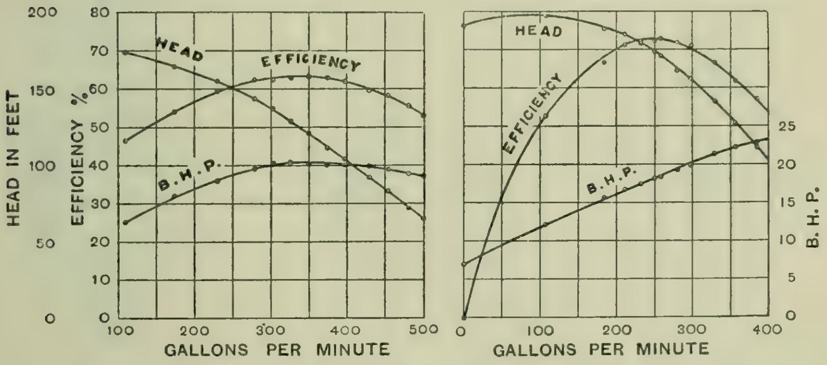


In the description of the mine-drainage pump (page 26) the authors seemed to set the pump down for a very large duty. In June last he had noticed a letter in the "Zeitschrift für das gesamte Turbinenwesen," from one of the staff of Messrs. Mather and Platt, which evidently referred to the same pump, as the duty was exactly the same. It was stated there that the pump actually on its official test at 1,450 revolutions per minute gave an efficiency of 80·7 per cent.

He would like to ask the authors whether that pump and the one described in the Paper had ever been actually run at 1,450 revolutions per minute, and whether its duty when installed was not 1,800 gallons a minute, 950 feet at 970 revolutions per minute. If that was so, it seemed rather strange that a pump of that size should have been designed to be capable of dealing with 2,000 feet, when its actual duty was only 950 feet, unless it was to substantiate the claim in the Paper of its being the largest pump of its type in the world.

Test of Centrifugal Pump (Holden and Brooke).

FIG. 27.—*Self-Regulating.* FIG. 28.—*Without Self-Regulation.*

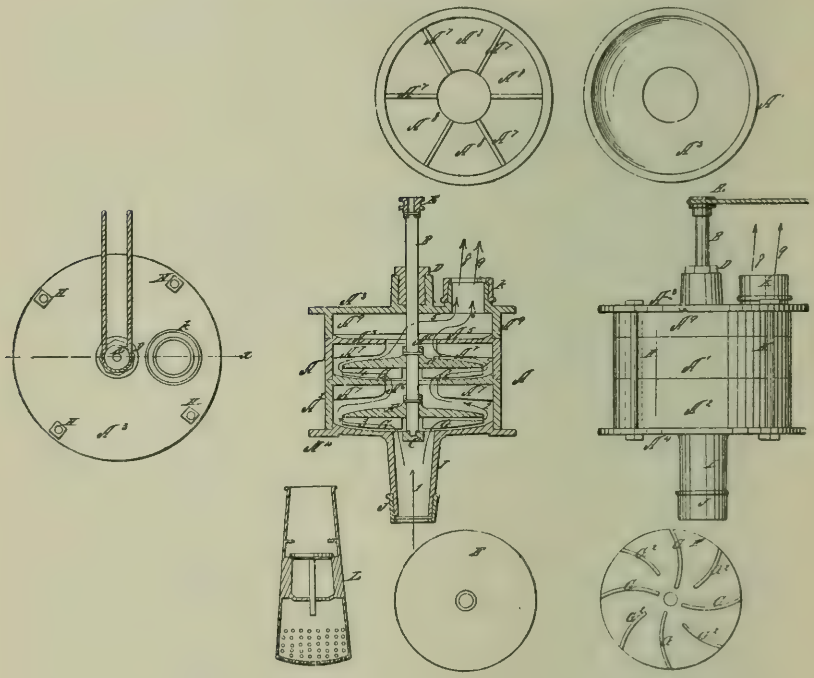


Mr. J. F. SCHUBELER did not wish to open a serious controversy as to the real inventor of the high-lift centrifugal pump. It was a commonly known fact in engineering that every invention had its pioneers, and that it was practically impossible to trace one

(Mr. J. F. Schubeler.)

invention as being the outcome of one man's work alone. The authors mentioned the interesting fact that already in 1851 John Gwynne had invented a multiple-stage pump, but five years before that date Mr. W. H. Johnson in America had invented the pump shown in Fig. 29, which was a three-stage pump already using impellers with curved vanes shrouded on one side. The pump, however, had no guide-vanes. He was of the opinion that the multiple-stage pumps of Osborne Reynolds in 1875, 1887 and 1895, in which last-named year Professor Reynolds was said to have collaborated with Messrs. Mather and Platt, did not differ in principle from the first-named ones, and it could therefore not be claimed that they were a novelty. The characteristic feature of

FIG. 29.—*Three-stage Centrifugal Pump.* W. H. Johnson, 1846. (U.S. Pat. 4426.)



all those pumps was that the impellers had open radial vanes and unshrouded sides, and that the water was delivered from the impeller direct into the overflow spaces built into the surrounding casing without the interposition of a special diffuser device, which was the most essential feature of the modern high-lift pump or turbine-pump.

He could not agree with the authors' statement that the Reynolds pump of 1875 showed already the elements of such a device, as the "tangent guide-vanes" shown in Fig. 2 (page 9) were only to be considered as a means for regulating the water quantity of the pump. That was confirmed by the fact that in later designs the practice was dropped, as it certainly would not have been if the inventor had recognized the importance of a suitable diffusing device. What was covered by the Reynolds patent were the ribs provided in the overflow spaces to give the water a better guidance to the next impeller, as the inventor probably had learned from experience that with his radial impeller-vanes the water in the suction space revolved with the impeller. That was always found where the inlet angles of the impeller-vanes were not suitably dimensioned to ensure a radial inflow direction of the water. That Reynolds only claimed that was clearly stated in the wording of his claim given on page 10—" . . . that the fluid, after leaving the moving passages, is received into fixed passages, so formed as to deprive it of all velocity of whirl."

The characteristics of the modern turbine-pump were that each impeller was surrounded by stationary guide-vanes, which were generally separate from the overflow pieces or casing, with diffusing channels shaped in accordance with scientific laws, in which the great velocity of the water or its kinetic energy was transformed without shock into pressure energy. The impellers themselves were shrouded and fitted with curved vanes. It was therefore evident that the Reynolds pump did not comply with this definition, the shorter guide-channels mentioned by the authors belonging to an era prior to that of the modern centrifugal pump, and not being identical with diffusers in the proper sense of the word. It was a generally known fact that the credit of an invention in engineering

(Mr. J. F. Schubeler.)

was given to the man or firm who was able to start the commercial application of the invention. If, therefore, the Hon. Sir Charles Parsons was acknowledged to be the inventor of the steam-turbine, it could not be claimed for Professor Osborne Reynolds that he had started a similar commercial application for the turbine-pump. That merit must be accorded to Sulzer Brothers, who in bringing out the latter did not collaborate with Professor Reynolds. This firm had built centrifugal pumps for low lifts since about 1860, and in a catalogue of about 1873 recommended centrifugal pumps up to a lift of 45 feet for large quantities.

Owing to the commencement of the application of electricity, a new development took place from the year 1890. It was possible to build pumps for high speeds to be driven by electric motors, and the pumps could then be coupled direct. The first multiple-stage pump from which the turbine-pump was developed was a vertical three-stage one built in 1894; it was not fitted with pressure diffusers and only had guide-vanes for the suction. In 1896 the first high-lift centrifugal pump with diffuser-vanes was brought out, the one shown in Fig. 13 (page 19), for the Geneva Municipal Water Works. The pump lifts 5,000 gallons to 460 feet, and has an output of about 1,000 h.p. That first four-stage pump had two pairs of impellers, the impellers of each pair being arranged back to back to eliminate the axial thrust. The water passages were of a somewhat complicated shape and a simplification appeared in 1898, the general arrangement of the impellers, however, remaining the same. That type had still some inconveniences—it was rather expensive and took up much space—but on the whole had given entire satisfaction. The Horcajo installation mentioned in the Paper was supplied with that type of pump. The latest step in development, however, was embodied in a pump of 1904 where the impellers were fitted with inlet openings all located on the same side. That type gave the shortest and simplest waterways with slightly increased efficiency. To overcome the axial thrust, an automatically working balancing device was provided at the pressure end of the pump on very similar lines to those shown in the Paper, Fig. 15 (page 22). It was interesting to see, from some curves by the authors, the influence of differently shaped impeller-vanes, and it would have been interesting if the authors had drawn some conclusions about the angles to be adopted, etc. The impeller with backwardly curved vanes had proved to give the greatest satisfaction with inlet angles of about 15° and outlet angles of about 30° to the tangent. Impellers with forwardly bent vanes did not give as good results, owing to the fact that greater velocities had to be transformed into pressure at equal circumferential velocities. The forwardly bent vanes had also the disadvantage that, when the pump worked with larger quantities, the danger of overloading the motor was greater than was the case with the backwardly bent impeller-vanes, which with an increased amount of water gave a decreased head. This could be derived from the diagram of the outlet velocities.

He thought the Paper should have mentioned other systems of centrifugal pumps, such as those put forward by Professor Rateau, Jäger, etc. Those systems differed from the Sulzer pump in their means for taking up the axial thrust, which constructional detail has become the essential and distinctive feature of these types. Rateau overcame the axial thrust by giving the shroud face on the suction side a larger outside diameter than the one on the opposite side of the impeller. Each impeller was intended to be balanced in itself. Jäger (Worthington) also balanced each impeller in itself by providing a balance-piston of the diameter of the suction opening on the shrouded face opposite the suction. Each of these devices had its advantages and disadvantages. Sulzer's could claim for their device that it worked automatically, was easily accessible and ensured the smallest internal losses. The device was applied to the centrifugal pump from steam-turbine practice, where dealing with much higher axial thrusts it had given the best results. It differed from the Mather and Platt arrangement in that in place of the internal grease lubricated bearing in the pressure-chamber it had an outside bearing, bolted on to the cover, the balancing water flowing out from the last pressure stage along the shaft under the balance-piston, and from there either back to the sump and some intermediate stage or through water-jackets of the bearings back to the sump. That balancing device had given the highest satisfaction

(Mr. J. F. Schubeler.)

even with gritty and sandy water. Piston balancing-devices had more internal leakages and did not as a rule work automatically; consequently, if the pistons wore out, the balancing was endangered and an axial thrust of considerable amount produced. He further mentioned the application of the turbine pump for sinking purposes, the first type having been built by Sulzer Brothers and exhibited in Düsseldorf in 1902. The horizontal pump, however, still had the widest application, especially for mining, for which purpose over a dozen pumps with heads exceeding 2,000 feet and outputs of over 1,000 h.p. were supplied by Sulzer Brothers during the last year. This firm had also built a single-stage pump delivering about 22,000 gallons per minute with a head of about 500 feet, an output of 4,000 h.p., and an efficiency of 80 per cent. This latter figure, he stated, was nothing unusual for large units, and in some cases 85 per cent. efficiency had been ascertained. The efficiency curves of the Sulzer pump given in Fig. 14 (page 20) applied to the first built Sulzer turbine-pump and not to a modern one. The speaker exhibited some lantern slides illustrating typical applications of turbine-pumps, and a section of a horizontal multiple-stage type built in 1904.

Mr. WILLIAM H. PATCHELL (Member of Council) said three makers had already spoken, but he would speak as a user. Mr. Millington had mentioned that it was not altogether a question of efficiency but a question of upkeep whether a centrifugal pump was used or not in a mine. The authors might have mentioned in connection with the Horcajo pump the interesting tests which were made, not by the makers of the plant, but by the engineer of the company using it. One year after it had started working the efficiency was 76 per cent., and it was tested five years later when the efficiency was also 76 per cent., although during the interval it only stopped 16 hours a month. He thought that was a good record of reliability for a turbine-pump. He considered harm had been done to the high-lift centrifugal pump because people took it up too lightly. In the early days every agricultural implement maker used to make a centrifugal pump. When they heard that high-lift pumps were being made, makers thought it was only a matter of putting a few pump-runners in series, and did not pay the necessary attention to the interior finish of the pump. When he first saw the high-lift centrifugal pumps he was immensely struck with the difference between those made in this country and those made on the Continent.

Fan Pits Pumping.

FIG. 30.—*Diagram showing Centrifugal Pumps and Piping Underground.*

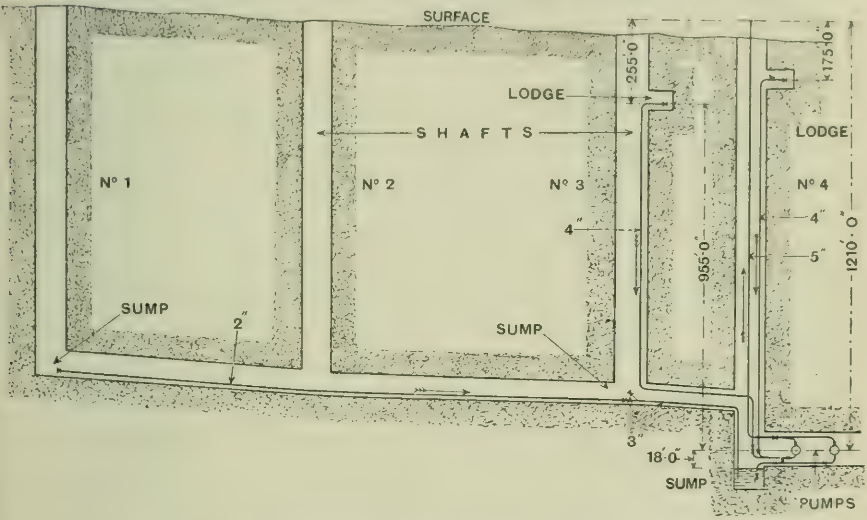
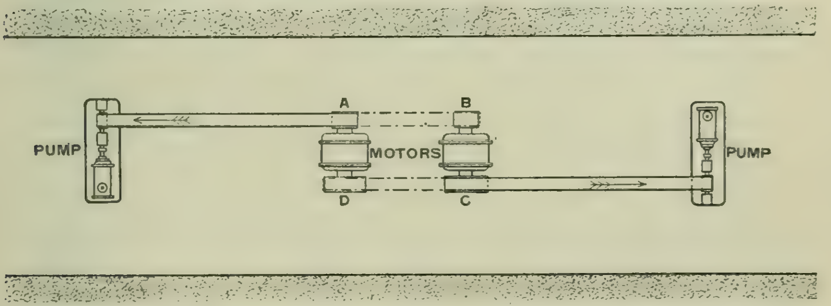


FIG. 31.—*Sketch showing relative position of Pumps and Motors.*

Pulleys A, B, C, and D are interchangeable. Direction of rotation of motors can be reversed.



(Mr. William H. Patchell.)

He had thought it might be of interest to the Members to see a diagram with particulars of a pumping equipment which was carried out by Messrs. Sulzer to his specification in South Wales. Figs. 30 and 31 showed two views, the lower being a plan and the upper a diagrammatic section. The problem was to deal with the water from three different pits. The shaft No. 1 only had a sump, shaft No. 2 had no water to be lifted, No. 3 had a lodge room about 250 feet from the surface and a sump. The other shaft, No. 4, had a lodge room about 170 feet from the surface and also a sump. The shafts had not been equipped with pumps. The water had been handled by winding it in barrels, but he persuaded the management to put in high-lift centrifugal pumps, and it took some time to persuade them to allow him to introduce such a novelty as putting the pump at the bottom of a U-tube. Some extra pipe-friction was incurred by so doing, but the labour of getting up the steam in the boilers at the three separate shafts was saved. Therefore there was a saving of three engine-drivers and stokers, and the men who used to handle the buckets. As there was no winding at the shafts, steam had to be raised whenever the pumping was done, which was a few hours a week. One man now attended to the plant. The water from the lodge room in No. 3 shaft, which was 250 feet from the surface, ran down 955 feet from the lodge room to the pump-room which was placed just above the sump. A U-tube was taken from the lodge room through the pump-room up to the surface. The pump handling water from No. 3 lodge room also had to handle water from No. 4 lodge room, not at the same time of course, so that at one time the pump had to work against 250 feet head with the head due to the friction in the pipes added, and at another time pump against 175 feet static head plus the friction in the pipe. To save any chance of a breakdown he put in two pumps and two motors. They were belt driven owing to the fact that only alternating current of 25 frequency was available. That necessitated a compromise in the design of the two pumps used. The motors had two pulleys, one at each end.

The left-hand side of the diagram, Fig. 31, showed the pump running with the smaller pulley on the motor, giving a lower speed on the pump. As belted, that pump would lift from the lodge rooms. The pump at the right-hand side was running at the higher speed necessary to the pump from the sump to the surface. Under those conditions it was not possible to get the high efficiency that could have been attained had the lodge-room pump been arranged to pump against its own head of 250 feet only, and the sump pump designed for 1,200 feet lift. In considering the efficiency of high-lift centrifugal pumps, the quantity of water pumped affected the question immensely. The larger the quantity in proportion to the head, the better the efficiency. With only a small quantity and a high head, a centrifugal pump would make a very poor showing compared with what could be done when handling a larger quantity of water. The efficiency of the two pumps was as follows:—

Static Head.	Pumping Head.	R.P.M.	Gallons per min.	Efficiency %.
Feet.	Feet.			
1,228	1,262	3,000	80	56·5
255	360	1,800	150	62·75

He had not got the efficiency for the third duty, which only had 175 feet head and 150 gallons a minute. The pumps were of Messrs. Sulzer's high-lift and eight-stage type. The motors were connected to a 3-phase circuit, 25 cycles, 2,200 volts, 720 r.p.m., the rated full load output of each being 62 b.h.p. They were mounted on slide rails and drove the pumps by belts 12 inches wide. He believed that was the first time centrifugal pumps had been used in the bottom of a U-tube, though it had been done several times since he had described the installation in South Wales three years ago, but he thought it might be of interest to the Meeting and be useful to some of the Members to show it again.

Mr. RICHARD W. ALLEN was sorry that the discussion was not following the lines suggested by the authors, as he was looking forward to hearing the criticisms on the design of the turbine-

(Mr. Richard W. Allen.)

pump. The authors had used the term "turbine-pump," but he did not know whether they purposed adhering to that title. He himself would prefer the term "turbine centrifugal pump," because, as had been pointed out by Dr. Unwin, there was very little difference between the centrifugal pump and the turbine-pump. There was one paragraph in the Paper which he was glad to see, and that was the question as to whether the disk should be shrouded or not, as this had been a very contentious point for many years past with designers of centrifugal pumps. There was conclusive evidence from the tests carried out by the authors that the shrouded disk was infinitely superior to the unshrouded disk.

The authors showed on pages 19 and 22 two forms of turbine-pumps, and, speaking as a designer and constructor of centrifugal pumps, he agreed with their conclusion, namely, that the design shown on page 22 had many advantages over that illustrated on page 19. In the latter the expense of constructing the large chamber, which held two, four, or more disks, was exceedingly great, whereas according to the design shown on page 22 the chambers were made separate, being held together by bolts, and the construction was of a simpler character, thus rendering the castings easier to manufacture. He would like to ask the authors whether they were satisfied with the design of the internal bearings as shown in Figs. 15 and 18 (pages 22 and 26). It was necessary to bear in mind the very high speed at which the pumps ran, and the places in which they were erected, as they were sometimes under the charge of unskilled labour, which gave rise to the question as to whether the designer was right in placing the bearings inside the pump. He would have preferred to see them constructed outside the pump—as, for instance, the left-handed bearing in Fig. 18—but perhaps the authors had very good reasons for placing the bearings inside.

He observed that the authors mentioned (page 27) that the series impellers were constructed of phosphor-bronze, and he would like to know whether they considered that metal the most suitable for such very high duties, and whether they had in their experience noticed any corrosion or erosion of these impellers. He believed most people who had constructed that class of machinery had in some cases experienced both. The boiler feed-pump as described on page 29 was a very fine piece of apparatus, but it appeared to be of an extremely complicated nature. He believed pumps were now made with only one disk delivering water into boilers at over 200 lb. pressure, and he thought, if turbine centrifugal boiler feed-pumps could be simplified and the stages cut down as much as possible, the field for these would be considerably widened.

Mr. G. P. **Mair** was very pleased to see that Mr. John Gwynne's specification was mentioned by the authors, who said that the specification contained many claims. The previous day he had been looking through a copy of the specification and noticed that Mr. Gwynne showed illustrations of centrifugal pumps drawing from jet and surface condensers. It was only quite recently that centrifugal pumps had been used for that purpose, notably the Le Blanc condensing plant, and he believed Messrs. Worthington also made a pump of that description, as did the Kinetic Air-Pump Syndicate. He had been greatly interested in the pumps for the Kinetic Air-Pump Syndicate, pumps which were giving very good results, but the question of using pumps with surface condensers, and also of the multi-stage turbine pattern, had probably not developed as quickly as might have been expected, owing to the fact that it was difficult to obtain any form of motive power. For instance, boiler feed-pumps and pumps drawing from surface condensers required to run at very high speeds, 2,000 and 3,000 revolutions per minute, and in early days it was practically impossible to drive pumps as fast as that. It was interesting to note that Mr. John Gwynne showed a multi-stage turbine-pump in the year 1851, and at the same time foresaw the future of centrifugal pumps for drawing from surface and jet condensers.

With regard to the design of the Mather and Platt pumps, he would like to ask the authors a question. The balancing arrangement shown and fully described by Mr. Millington was no doubt a very pretty arrangement on paper, but when dealing with mine water and when sinking in shafts there was a large amount of grit to be dealt with, and the leakage water allowed to pass the

(Mr. G. P. Mair.)

balance-disk must be small, otherwise the efficiency of the pump was seriously affected. That meant that the balance-disk and the fixed surface must be in close proximity, and as grit in the leakage water passed between those surfaces which were rotating at a very high peripheral velocity, serious wear must take place. It therefore became necessary to renew disks periodically. There were other ways of overcoming the end-thrust, which calculation showed to be considerable, sometimes amounting to 2,000 lb., and the question was whether the arrangement shown in the drawing of the Sulzer pump and also used by other makers was not preferable. Messrs. Sulzer placed the disks back to back to minimize the end-thrust as far as possible, and it appeared to him that that was the most reasonable way. At the same time a small thrust-bearing could be installed in case of emergency, because it was a difficult thing to cast disks all mathematically the same off the same pattern, and slight inequalities in a centrifugal pump made a very serious difference in the results.

Mr. W. H. ATHERTON said that engineers thought, not many years ago, that a head of 30 feet of water was about the economical limit of pressure for an ordinary centrifugal pump ; and even in the Mather-Reynolds turbine-pump fitted with guide-vanes, 30 feet per impeller or working chamber was the accepted practice. Thus for 60 feet head two impellers in series were used, for 90 feet head three impellers, and so on. During the past twelve years, however, pump designing had developed so much that engineers now did not hesitate to put 300 feet head on each impeller of a large multiple pump, as in the mine-drainage pump shown on page 26. But it still remained true that high heads and large capacities went best together, while high heads combined with small capacities resulted in comparatively troublesome and inefficient pumps. No one must expect to deliver, say, 50 gallons of water per minute against 1,000 feet head with the same simplicity and efficiency as 5,000 gallons per minute by means of a turbine-pump. For small quantities combined with high pressures, reciprocating pumps still held the field.

Professor Osborne Reynolds' idea of using regulating vanes or adjustable guide-channels, though quite common in the case of water-turbines, proved to be too expensive for adoption in commercial pumps, a sufficiently high efficiency being obtainable by the use of fixed guides for a moderate range of output.

A notable achievement in the application of turbine-pumps was the pioneer installation of three multiple pumps in series at different levels, installed at a silver mine in Spain by Messrs. Sulzer Brothers in the year 1898, and referred to on page 25. These pumps forced 1,000 gallons per minute against 1,500 feet total head, and replaced several other pumping sets which had proved failures. The whole plant was greatly to the credit of the makers, and opened the eyes of other engineers to the possibilities of revolving pumps. It would be interesting to learn what renewals have been necessary to these pumps since their installation thirteen years ago.

It was a matter of some historical interest that two Sulzer type turbine-pumps, made by Messrs. Mather and Platt, were on view at the Glasgow International Exhibition of 1901, where they attracted much attention. One of these was shown coupled to a variable-speed motor, and delivered a high-velocity jet of water through a fire nozzle. The larger one had a capacity of 1,250 gallons per minute at 90 feet head, and was afterwards installed at the Newcastle-on-Tyne Electric Power Station as a circulating pump.

There was one original feature in the mechanical design of the Mather pump that might well be emphasized, namely, the excellent system of building up multiple pumps in a number of identical units or sections; this facilitated both manufacture and overhauling, as well as decreasing the cost of spares and renewals. In this respect, at all events, the Mather design had an important advantage over the Sulzer type, which did not so well meet the requirements of economical manufacture. In the latter the cast-iron casings were extremely complicated, involving expensive pattern-making and much difficult cored work in the foundry. Moreover, the Mather design lent itself equally well to either an odd or an even number of impellers in series, while the Sulzer pump must have an even number. He referred to the type of pump illustrated in the Paper,

(Mr. W. H. Atherton.)

Fig. 13, (page 19), though there might have been subsequent developments.

It must be admitted that the total omission of the vortex or whirlpool-chambers from the Sulzer pump had resulted in a desirable simplification and compactness in the more modern designs of multiple pumps. It was not clear, however, why a whirlpool-chamber should still be generally provided in a single-impeller turbine pump. If whirlpool-chambers could be omitted without sensible loss of efficiency in multiple-wheel pumps, then why should they not be omitted in single-wheel pumps?

As to the precise distinction between a turbine-pump and a centrifugal pump, it seemed to the speaker that a turbine-pump was merely a particular type of contrifugal pump, namely, one which was provided with divergent guide-passages beyond the impeller. Even if not generally recognized at present, this distinction would be a convenient one to make. Thus every turbine-pump was a centrifugal pump, but not every centrifugal pump was a turbine-pump.

There were one or two queries he would like to ask the authors. Firstly, with reference to the remark on page 8 that "Gwynne's specification contains many claims, and amongst other interesting designs he shows a reaction impeller, now used for self-regulation." He would like to ask whether Gwynne's reaction impellers acted on the same principle as the now well-known reaction impeller used in the Rees Roturbo pump, which was claimed to be quite an original feature of that pump. Secondly, on page 23 the authors said: "The impeller is turned all over outside to reduce loss by skin friction, and with the same object it is usual to use as many wheels as the circumstances will otherwise allow of." Some years ago the speaker had had something to do with designing turbine-pumps, and it was always an object, at least as regards economical design, to reduce the number of wheels to as few as possible. Skin friction was proportional to the surface, amongst other variables, and when using many wheels there was a large surface exposed to skin friction. On the other hand, it was possible by using many wheels in series to keep down the diameter of the wheels for a given head and revolutions, so that the reduction in diameter might compensate for the increase in the number of wheels, both as regards first cost and skin friction. At all events the point as to why it was customary to use many wheels rather than few wheels seemed to require a little further elucidation.

Mr. E. R. **Dolby** said he would like to raise a small secondary point regarding testing, and to ask a question. He used a considerable number of turbine-pumps for the purpose of promoting reinforced circulation in long loops of mains, extending perhaps half a mile. There was a very small head and a considerable volume. He required to vary the volume of water flowing in these loops, and in order to do so he varied the speed of the motor or whatever drove the pump, but he could not measure the actual volume of water going through the pipes except by finding out what the differential head was between the suction and delivery, and then referring to quantitative tests. Simply putting a pressure-gauge on the suction and another pressure-gauge on the delivery pipe meant that when the pump was not working the two gauges read alike, and when the pump was running the reading on the suction side went down and the reading on the delivery side went up. It was not very convenient for the engineer in charge to read the one and then the other and take the difference, and therefore he looked about for some more convenient way of doing it. He found the mercury-column gauge unsatisfactory and sketched out what he might term a double-pressure gauge—two Bourdon gauges with a pointer to read zero at the top of the dial and to move either way—and he had several such instruments made. Theoretically the design looked all right, but in practice the hand could not be kept to zero permanently, and constantly required adjustment. His question was whether, in testing pumps, the authors had any ready method of directly reading the differential head.

Mr. A. E. L. **Chorlton**, replying to the discussion, thanked the members for the vote of thanks they had passed to Dr. Hopkinson and himself. The Paper was as far as possible kept entirely to one

(Mr. A. E. L. Chorlton.)

particular subject, and no attempt was made to cover broad ground. It was quite true that in writing such a Paper it was possible to collect from the catalogues of various makers and to describe their methods of design, but they had particularly avoided doing any such thing. They had wished to trace the work of Professor Osborne Reynolds and the developments arising directly from it, leaving others to judge of the way in which it had affected other turbine-pumps.

Dr. Unwin had given a very interesting history of what had been done in years gone by, and had referred to the Osborne Reynolds pump being a Thomson turbine reversed; that was so, and it was so described in the Paper. The point was that Osborne Reynolds saw the possibility of reversing a turbine while other people before him apparently did not do so. The velocities in the diagram of page 13, to which Dr. Unwin referred, were actual velocities relative to the wheels and in the passages.

Mr. Millington had given a long disquisition upon his particular class of pump (page 38), which he believed was built up upon the experience gained with the Reynolds pump. He did not think it was necessary to deal with any point Mr. Millington had mentioned, for the simple reason that he explained each point as he went along himself, except perhaps one, and that was reliability. He quite agreed that reliability was very important indeed, but if the authors had described the particular details of the pumps with this end in view it would have meant a Paper of much greater length. He also agreed with Mr. Millington that the end balance was the most important point in reliability. Both the Messrs. Sulzer's and Mr. Millington's balance devices were good ones and in common use, but he ventured to think the one described in the Paper was the best one. The authors had had experience with the other types, and found, particularly when dealing with dirty, gritty water, that something further was required than a single balance.

Mr. Schubeler had given some interesting information with regard to an early American series-pump (page 42), but it was not a turbine-pump, having no guide-vanes. He could only conclude from his remarks that Mr. Schubeler had quite failed to understand the principles of Professor Reynolds' designs, which he regretted, as it had been one of the principal objects of the Paper to elucidate them.

Mr. Patchell's description of his work in South Wales was most interesting, but he himself was more interested in the arrangement of the motors and pumps than in the U tube. Mr. Patchell's arrangement (page 48) was very neat in securing exactly what he wanted and providing standbys.

With regard to the bronze used for the wheels, bronze was only necessary for special conditions. The term "phosphor-bronze" was, he admitted, used rather loosely as a commercial expression. Bronze of suitable characteristics might be used as an acid-resisting material or to obtain greater strength for high speeds and heads, and in cases referred to in the Paper it was used for one or other of these reasons. The cast-iron impeller was little used now, although no doubt it met requirements in many cases. As to the internal bearings, at first sight it would be concluded they were not a good arrangement, but in practice they had proved entirely satisfactory. If reliability were the main point, and the chief factor in reliability was the balance-valve, it was obvious that the balance-valve must be put in the most accessible position, and that was the reason it was put on the outside and not on the inside of the bearing. In that position it was easy to take the valve off without disturbing anything, adjust it and put it back. With a forced feed lubricator, feeding grease, the bearings gave no trouble at all. The boiler feed-pump shown illustrated the way a certain difficulty in design had been met. It was not a single impeller pump, because it was driven by a continuous-current motor and ran at a slow speed.

Mr. Mair also made a strong point of balancing (page 51), and he appeared to prefer the back-to-back arrangement of impellers. The back-to-back arrangement of impellers as in the early Sulzer pumps was somewhat deceptive. In theory the impellers balanced, but when wear occurred in any part of the pump they got much out of balance. A simple type with an effective balancing arrangement was in his judgment better than back-to-back. Further, the back-

(Mr. A. E. L. Chorlton.)

to-back system sometimes made a centre bearing necessary, which was certainly to be avoided if possible.

In reply to Mr. Atherton's remark in reference to reaction impellers (page 54), he might say that the reaction impeller shown in the original specification of John Gwynne had vanes with much backward curvature. With reference to the number of wheels, he would observe that the power absorbed in friction resistance varied approximately as the fifth power of the diameter and the cube of the number of revolutions per minute, and consequently so far as this factor in the efficiency was concerned, it was preferable to use a number of surfaces of small diameter with low peripheral velocity rather than a few surfaces of larger diameter with higher peripheral speed. Later experiments by Messrs. Gibson and Ryan have shown that disk frictional losses were not as large as generally supposed, consequently the advantages of using a greater number of wheels with lower peripheral speed was not as great as it formerly appeared to be; but still in a case recently examined, the authors had found that a two-chamber pump gave a calculated efficiency of 81·5 per cent. at 750 revolutions per minute against 78 per cent. at 935 r.p.m. and 80 per cent. at 1,250 r.p.m. for a single-chamber pump of corresponding duty. As to the cost of manufacture, that might depend upon circumstances. Possibly as between a two-chamber and a single-chamber pump the single chamber would have the advantage, but with a multi-chamber pump the smaller diameter with a larger number of chambers would be cheaper.

Mr. Dolby had asked (page 55) whether there was a simple method of readily reading the differential head between the two sides of the pump. In ordinary practice it was customary to use standard gauges which were easily calibrated, one for suction and one for delivery, and to make any allowance that might be necessary for the difference in level. He did not know of any more convenient arrangement.

Dr. EDWARD HOPKINSON also replied. He observed that a good deal had been said that evening about the application of the term "turbine" to the turbine-pump, and some doubts had been expressed as to its suitability. He thought the simple explanation for the pump receiving that name was that it was so baptized by the inventor, and not unnaturally it had continued to bear it. There was, however, to his mind a very real distinction—and he could not quite follow Dr. Unwin in that point—between a turbine-pump and other forms of centrifugal pumps. All pumps in which head or lift was imparted to the liquid by centrifugal forces acting thereon by rotating it in a revolving impeller came under the term "centrifugal pump." But such pumps might be divided into three principal classes. The liquid as it issued from the impeller had a certain head due to the centrifugal forces acting upon it from its rotation in the impeller. It had also kinetic energy due to the velocity of whirl imparted to it. This latter might be dealt with in different ways:—

First, there might be no attempt to convert this kinetic energy into potential energy of head, the impeller being simply surrounded with a collecting chamber, which received the liquid from the impeller and conducted it to the delivery-pipe. The older centrifugal pumps were of this character.

Secondly, the impeller might be surrounded by a series of guide-vanes, enclosing expanding passages, which received the liquid issuing from the impeller and converted its kinetic energy or a part of it into potential energy of head as its velocity diminished in passing through the expanding passages. Such pumps were properly described as "turbine-pumps"; and the Osborne Reynolds pumps, the earlier multiple-chamber pumps of Sulzer, and the pumps described in the Paper were of this type.

Thirdly, the impeller might be surrounded by a chamber in which the rotating liquid formed a vortex, which also converted the kinetic energy or a part of it into potential energy of head. The liquid was collected from the periphery of the vortex by a suitable collecting chamber and conveyed to the delivery-pipe. Such pumps were conveniently termed "whirlpool-pumps," and the large pumps described by Dr. Unwin afforded a good example of pumps of this character. The three classes overlapped each other, as the collecting chamber of the first type might be constructed to act

(Dr. Edward Hopkinson.)

to some extent as a guide or diffuser passage; or as a whirlpool-chamber; or the guide-passages of the second type might be surrounded by a chamber acting as a whirlpool-chamber with a view to further converting the kinetic energy, which the liquid might still possess after issuing from the guide-passages, into potential energy. Many single-chamber turbine-pumps were to some extent of this character.

Finally, a whirlpool-chamber pump might have a diffuser passage exterior to the whirlpool which conducted the liquid from the whirlpool to the delivery, and was so constructed as to again convert some portion of the remaining kinetic energy into potential energy. In his judgment the chief improvements which would be made in centrifugal pumps in the future would be due to a combination of these principles suitable to the particular circumstances, and he thought that the recent researches of Dr. Gibson on the flow of water through expanding passages of different sections and with different angles of divergence would be of great assistance to designers.

Communications.

Mr. A. MARSHALL ATTACK wrote that on page 13 were given curves showing a comparison between the relative velocities through impellers; from these it would appear that, although the velocity was less in the Mather-Reynolds pump, it was superior in one way to the modern pump, in that the reduction in velocity of the water while passing through was more even. The sudden drop in velocity in the latter, directly after entering, caused eddies, and so reduced the efficiency somewhat. It would appear that the reduction in velocity should be even throughout. The curves, Fig. 7 (page 14), showed clearly how necessary it was for the form of blade to be suitable for the work to be done. Undoubtedly the poor result from the reaction wheel "D" was due to the unsuitability of the guide-passages, both as to angle of entry and area. This form of impeller, with suitable guide-blades, should give a much better result than was apparent from the curves. There were manufacturers who constructed their impellers with a high degree of reaction, whereby they maintained that they obtained the highest efficiencies in addition to self-regulation. With regard to the remarks on short and long guide-passages, the short passages were analogous to the volute of an ordinary centrifugal, giving rise to a kind of instability of flow, and allowing the stream to break up at higher velocities; this was prevented by the longer passages which give a more gradual conversion of velocity into pressure. From this it would appear desirable to create as much head as possible within the impeller, there being less opportunity for this breaking up of the stream within the impeller than in the guides or casing.

Referring to the boiler feed-pump (page 29), the writer would like to know the reason for adopting 1,270 revolutions per minute, which necessitated building the pump in two units. This speed was low for this type of pump, making the set costly, having regard to the output. He considered it would have been preferable to put in a 6-stage pump running at 2,800 revolutions per minute. This would have reduced the diameter of the impellers, with consequently less friction and better efficiency. The writer had designed boiler feed-pumps for similar duties, running at the higher speed, which had given every satisfaction in continuous work. This speed appeared to be standard practice with turbine pumps for this class of work. These pumps could only be used on a comparatively large steam plant, requiring not less than 100 gallons per minute, and would show a saving in power of over 50 per cent. over steam piston-pumps for the same duty.

The Hon. R. C. PARSONS wrote that in the year 1875, at the request of the late Sir William Anderson, F.R.S., whilst a pupil in his works, he studied the principle and design of the Appold centrifugal pump, as the laws which governed the discharge and the efficiency were then so little known. After much consideration and numerous experiments, which were described in a Paper * read

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* Proceedings, Inst. C.E., 1877, vol. xlvii, page 267.

(The Hon. R. C. Parsons.)

by him before a Students' meeting of the Institution of Civil Engineers, the laws which governed both those unknown quantities were explained. Subsequently in 1877 a Paper * was contributed to the Institution of Civil Engineers by Dr. W. Cawthorne Unwin, F.R.S., in which the results the writer published were made use of by Dr. Unwin to reduce the laws of the centrifugal pump to mathematical language. This Paper, he believed, was regarded as embodying all the knowledge necessary to design a correct centrifugal pump.

In the experiments referred to, it became evident that at some point in the interior of the pump the particles of water must be made to attain a velocity equal to eight times the square root of the head against which it was required to pump, and that this velocity must be generated and then reduced with as little suddenness as possible, so as to give the best efficiency. A pump was then designed on this principle, and an efficiency of 67 per cent., as registered on a Morin dynamometer, was obtained. Since then little improvement in the efficiencies has been obtained, except in very high lift pumps, and this was also shown would be the case by the experiments referred to.

In regard to pumping by means of centrifugal pumps in series, the writer, when sinking a well in the South of England in the year 1878, used two centrifugal pumps in series, and prepared to use a third. These were belt-driven and worked remarkably well, but if an electric motor or a steam-turbine had been available, the work would have been more easily accomplished. From what he had just stated, he thought it followed that little improvement had been made in the centrifugal pump since 1876, except in regard to details, but that the great development of this method of pumping had practically become possible owing to the electric motor and steam-turbine being capable of supplying the necessary high rotatory velocity. There were, however, still many fields open for the use of centrifugal pumps adapted to special requirements, actuated by motive power such as he had mentioned.

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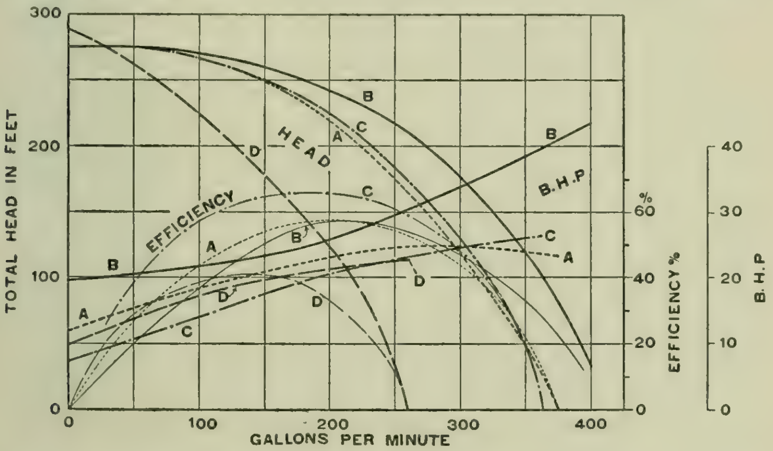
* Proceedings, Inst. C.E., 1878, vol. liii, page 249.

Mr. OWEN A. PRICE (Glasgow) wrote that the curves drawn in Fig. 12 (page 18) appeared to show such remarkable irregularities that it seemed worth while to examine them more closely. To do this, one set of curves—the 2,000 revolutions per minute set—had been replotted and the brake horse-power lines calculated for each of the guide-passages. The result was shown on Fig. 32.

The authors stated that the same impeller was used with all four guides, A, B, C, and D. It was well known that the power absorbed by a given impeller was proportional to the product of the peripheral velocity and the total momentum of the water leaving the impeller; that is, the power was quite independent of anything external to the impeller. The useful output of course was another matter, and was dependent on the guide-vanes as well as the impeller. In the experiments under consideration the same impeller in each case was revolving at the same speed in each of the tests, hence, for the reason stated above, the power consumption should vary solely with the quantity; therefore, neglecting other influences for the moment, there should be only one power line for all four guides A, B, C, D. The curves as replotted showed considerable differences in the power lines for the various guide-

FIG. 32.—2,000 *revs. per min.* *Curves* (Fig. 12) *with calculated B.H.P. lines added.*



(Mr. Owen A. Price.)

passages; not only differences in the amount of power absorbed but differences in the character of the curves. There would only be a single-power curve for the four guides if the conditions at entry to the impeller were exactly similar for each. Guide B differed in this respect from guides A, C, and D; the difference, by the way, was of a nature which might account for the different character of the power-line B; but, by all appearance, they were justified in saying that for guides A, C, and D the conditions were practically identical. The angles and curves of the directing vanes were alike and the resulting tangential velocities of the water entering the impeller-eye would be practically identical for the three guides when passing the same quantity of water. Hence, for the curves A, C, and D one would at least expect a single-power line, and even for B one would expect only a slight deviation increasing as the quantity increased. At the zero quantity one would expect identically the same power with each of the four guide-passages, and the fact that they did not get it was sufficient evidence that in the experiments represented by the curves of Fig. 12 (page 18) there were other influences coming into play besides the mere changing of the guide-vanes. It was difficult to say just what these influences might be, but there were many things that occurred in practice, such as differences in adjustment and alignment in the several times the pump parts were assembled, possible air-leakage with some of the tests and not others, possible mechanical variations, warm bearings, etc., and also possible variation in the driving motors or instruments for measuring the power.

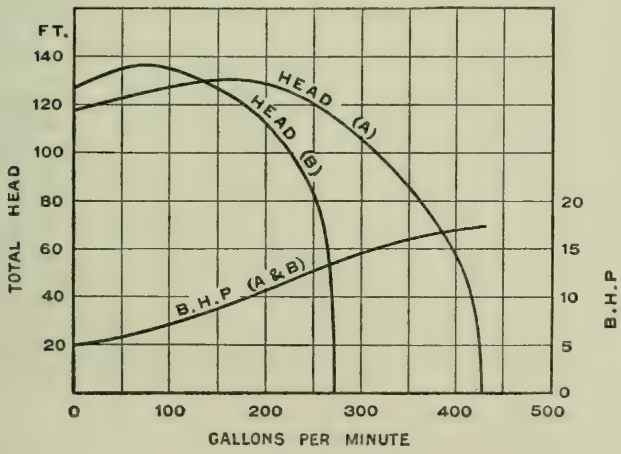
The writer once encountered a rather interesting and little suspected source of disturbance in some centrifugal-pump experiments. The water being pumped was circulated through two tanks passing over a weir-notch from the one tank to the other. When a very large quantity was passing, the water became perceptibly aerated in falling into the lower tank, and remained so for some little time. Decidedly better results were obtained after a week-end rest, when the water was comparatively free from air, than towards the end of a week during which the water had been particularly agitated. Every one interested in pumping would readily appreciate the effect of the aeration on the pump. These disturbances were of course only noticeable when very large quantities were being pumped; in the particular case the quantity was from 15,000 to 18,000 gallons a minute.

Fig. 33 had been prepared to illustrate the writer's point regarding the "single-power curve," when only guide-vanes were changed. This diagram represented two tests selected from a number of experiments carried through by the writer at the works of Messrs. Drysdale and Co. of Glasgow. In these two tests, guide-vanes of different throat width were employed, the same impeller and pump-casing being used each time. The difference between the guides was substantially the same as between the authors' vanes C and D, except that the return-passages were radial for both guides. The power curves were coincident to the limit of quantity of the small-throated vane, that is, to about 273 gallons, after which quantity the power line represented the large-throated vane only. The agreement of the plotted points for the

FIG. 33.—*Illustrating the Single-Power Line obtained with a single impeller and different guide-vanes.*

A = Wide Throat guide-vane.
B = Narrow Throat guide-vane.

Speed 1,000 r.p.m. constant.



(Mr. Owen A. Price.)

two vanes was really quite remarkable, and indicated the care exercised in attempting to secure similar conditions for the two vanes; however, as explained before, it was the natural thing to expect.

The writer was pleased to note the high head with the zero quantity reading from the authors' guide D, because a similar thing occurred in the small-throated vane on the writer's diagram, Fig. 33. The writer would like to ask how the authors explained this higher head with the smaller throated vane, for he had not been able to formulate a very convincing theory himself. The writer had two vague suggestions that he hesitated to put forward just now, for fear the authors might have some simpler explanation which they had verified by experiment.

Regarding the variation of the efficiency at different speeds in the authors' curves, Fig. 12, it was hardly conceivable that a variation could occur such as exhibited by guide C between the narrow speed limits of 1,000 to 2,500 revolutions per minute, and the writer would be inclined to look for some other cause for this strange behaviour. For very low speeds, efficiency was impaired by the preponderating influence of mechanical friction, and for very high speeds efficiency was reduced by excessive disk-friction of the revolving impellers. Both these influences would have a similar effect on all four guide-vane results, and evidently they could not account for the erratic behaviour of guide-vane C; certainly they could not account for 20 per cent. rise, from 1,000 to 1,500 revolutions per minute, and then 12 per cent. fall in efficiency from 1,500 to 2,500 revolutions per minute. It was an axiom in centrifugal-pump design that if the head was made proportional to the square of the speed and the quantity directly proportional to the speed, then the power varied as the cube of the speed. This was another way of saying that the efficiency remained constant under the head and quantity conditions stated. That this was true, subject to the frictional influences previously mentioned, was borne out by practical experience, and within the speed limits of the plotted tests the efficiency variation could hardly exceed, say, 4 per cent., depending on the dimensions of the pump parts.

Bearing in mind all the facts mentioned in this communication, the writer considered the curves of Fig. 12 (page 18) could not be accepted as truly depicting the influences solely due to the variations in the several guide-vanes A, B, C, and D.

Regarding one other matter, the writer ventured to point out that it was not strictly true to say that "self-regulation" could be obtained by such a guide-vane as the authors' "D" or by throttling at the eye as mentioned by them. Reference to the present writer's diagram, Fig. 33, showed that *power limitation* was a more correct term, for there was no such effect as was usually associated with the idea of "self-regulation," namely, a re-curved or horizontal brake horse-power curve, and which effect certainly did occur in the reaction form of impeller shown in curves Fig. 7 (page 14). However this term "self-regulation" might have arisen, even though it might have been by the enterprising advertisement of one particular pump, the writer did not think it was any use to deny that the term was very well understood by engineers, though its importance might be frequently much exaggerated. Literally considered, the term might have no sense, and etymologically treated it was difficult to follow the connection with the idea, familiar enough to centrifugal-pump builders; but the fact remained that, previous to the advent of the particular pump referred to, no term had been coined for this particular characteristic; and what had been, and was now in fact, a trade term had, in spite of its vagueness, assumed a definite sense in pump language.

Mr. GEORGE WILKINSON wrote to point out to the authors the fact that they had made no reference at all in their Paper to the question of electrical energy required in operating a turbine-pump for a given result, as compared with a three-throw reciprocating pump also electrically driven. So far as the writer's experience went, the turbine would take double the energy required by a three-throw pump. As to reliability of operation, there was little to choose between an electrically operated turbine-pump and an electrically operated three-throw pump; while the extra consumption in

(Mr. George Wilkinson.)

operating the former was a heavy price to pay for the small economy of space gained. Also as regards capital cost, the advantage was probably considerably in favour of the three-throw pump. If the turbine-pump when used as a boiler-feed pump were compared with a compound steam-pump of the long-stroke type, the comparison was even more unfavourable. A well-made compound steam-pump of this type would deliver from 120 lb. to 130 lb. of water into the boiler for every lb. of steam used. He would be glad if the authors would furnish some information in their reply as to comparative efficiency and first costs.

The AUTHORS wrote, in reply to the Communications, that Mr. Attack (page 60), in comparing the curves given on page 13, pointed out that the velocity through the Reynolds pump was more regular and did not suffer the same drop on entering the wheel as in the modern example. It was difficult to reproduce the Reynolds velocities exactly, owing to the entrance of the wheel being of a modified Francis form. The curves must not be regarded as standard curves but as examples of particular cases, and it might be noted that the velocities given on page 13 were based on the assumption that the section of the channel across which the flow took place normally was normal to the bounding surfaces, and was not the section measured circumferentially, which latter method was now frequently employed by some experimenters, making allowance for the weir coefficient at entrance. Mr. Attack in his communication had drawn attention to the low speed of the boiler feed-pump described. The authors agreed that 1,270 revolutions per minute was an unnaturally low speed for a pump of this duty. It was adopted because the pump had to be driven by a direct-current motor with a predetermined speed. Had the driving agent been an alternate-current motor or a steam-turbine a higher speed would have been adopted. In general, motor-driven pumps were in their experience limited in speed by considerations pertaining to the motor rather than to the pump.

The authors agreed in general with Mr. Price's examination of the curves given on page 18, and the discrepancies he pointed out (page 63) were no doubt due to the causes he suggested, the effect of which would be aggravated by the fact that the curves were taken from quite a small pump. The authors included these curves in the Paper for the purpose of illustrating the general effect of different forms of guide and return passages. The experiments were not made with a view to elucidating any other points. Probably the higher head with the smaller throated vane was due to local and irregular vortices being set up in the wider entrances, which would detract from the head set up by the centrifugal forces. Mr. Price's experience with aerated water was interesting, and similar effects had often been experienced by the authors. Probably many cavitation and erosion troubles which had occurred with pumps, especially those working with considerable suction lifts, were due to the presence of air in the water.

Referring further to Mr. Millington's remarks (page 41) on the mines drainage pump, the example he gave was of a similar pump run at a lower speed. The 1,450 revolutions per minute of the pump described in the Paper was a standard 3-phase motor speed for mine pumps. Mr. Millington correctly described the duty of such a pump at 970 revolutions per minute. The authors would further observe, in reference to Mr. Millington's remarks, that they did not recommend design D (page 18) for self-regulation as suggested, but merely stated that it had such an effect. They preferred using other methods for this purpose. The curves shown by Mr. Millington were interesting in that he showed the reduction of efficiency due to self-regulation, but at the same time they thought that it was possible to reach an efficiency of over 63 per cent., as shown by Mr. Millington, with self-regulation secured by other methods.

RECENT RESEARCHES AT THE NATIONAL PHYSICAL LABORATORY, TEDDINGTON.

LECTURE

By T. E. STANTON, D.Sc.,
Superintendent of the Engineering Department,

AT THE GRADUATES' MEETING,

Monday, 12th February 1912.

Dr. H. S. Hele-Shaw, F.R.S., *Member of Council*, in the Chair.

In putting before you a short account of some of our experimental studies in the Aeronautical Department of the National Physical Laboratory during the last two years, it will in the first place be of advantage, I think, if I begin by referring to the distribution of pressure over a flat plate normal to a current of air, and then gradually trace the changes due to the variation in thickness, form of the plate, and its inclination to the wind. As is well known in the case of normal impingement, Fig. 1 (page 72), there is, in addition to the pressure on the windward side of the plate, a reduction of pressure or suction on the leeward side, which for a square or circular plate is approximately 45 per cent. of the amount of the pressure on the front face, so that the resultant pressure on the plate is the sum of these two effects. Of these the former is the one which is least variable, as it is found that in the case of a flat surface against which air impinges normally, the pressure on the windward side at the centre of the surface is always $\frac{1}{2}\rho v^2$ (where ρ is the density and v the velocity), whatever the shape and size of the surface. The suction effect, on the other hand, which is due to the eddies of air breaking away from the edge of the plate is a very variable quantity, and is the source of nearly all the difficulties in aeronautical research work. In the case of normal impingement this variability is very marked when the ratio of length to breadth of the plate is varied. Thus, for the case of a flat plate 6 inches by 1 inch the value of the suction is increased from 45 per cent. of the windward pressure to 50 per cent. It is for this reason that the resistance of thin wires becomes so considerable and difficult to predict.

Fig. 1.—*Distribution of Wind Pressure on Circular Plate.*

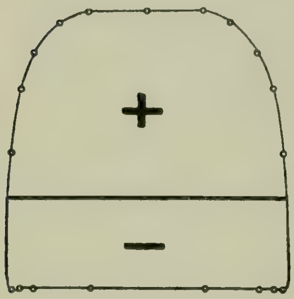
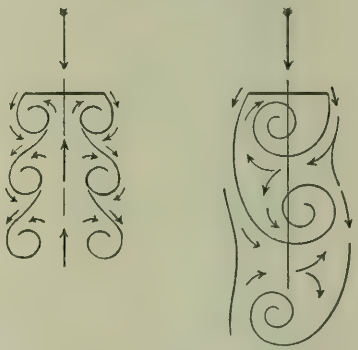
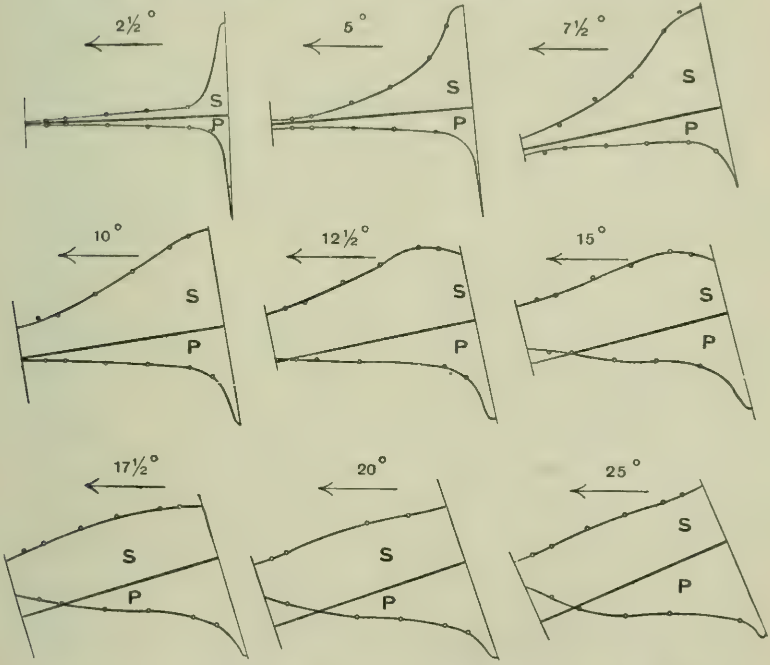


Fig. 2.—*Formation of Eddies at back of Plate.*



The characteristic of the suction, however, which gives the most trouble to the experimenter is its variation with mere size: for instance, if we put two square plates facing the wind, one 2 inches by 2 inches, and one 12 inches by 12 inches, the suction at the back of the 12-inch plate is approximately 25 per cent. greater than that at the back of the 2-inch plate. Due to this cause it is found that the resistance of a square plate 10 feet by 10 feet in the wind is nearly 18 per cent. greater than that of a 2-inch by 2-inch plate at the same velocity. It will be seen at once that unless the law of this variation is accurately known, quantitative experiments on models become useless as a method of predicting the magnitude of the forces acting on the full-scale machines or structures. One of the chief difficulties which is being encountered at the National Physical Laboratory at the present time is to determine what the frictional resistance of a full-sized dirigible balloon is from experiments on a model $\frac{1}{500}$ scale, and this is an instance of the above effect.

Fig. 3.—*Distribution of Pressure on Plates inclined to the Wind.*



The actual method of formation of the eddies at the back of a plate is a very difficult matter to investigate experimentally. Mr. Mallock, who has devoted a good deal of attention to the subject, states that the formation may proceed simultaneously from both edges, or alternately from one edge of the plate to the other, as shown in Fig. 2.* It is therefore easy to understand the well-

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* Proc., Royal Society, A., 1911, Vol. 84, page 490.

FIG. 4.—*Normal Pressure on Plates 3-in. × 1-in. inclined to direction of current.*

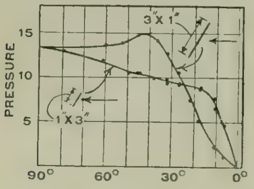
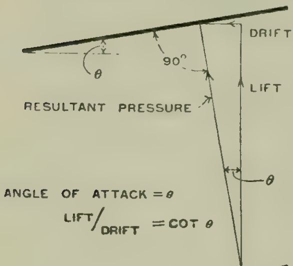


FIG. 5.
THEORETICAL CASE OF FLAT PLATE, NEGLECTING FRICTION.



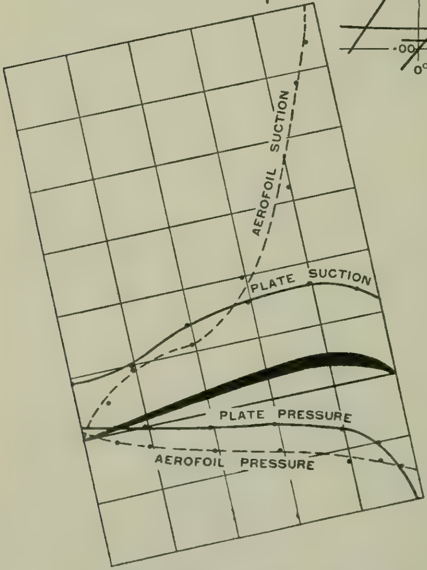
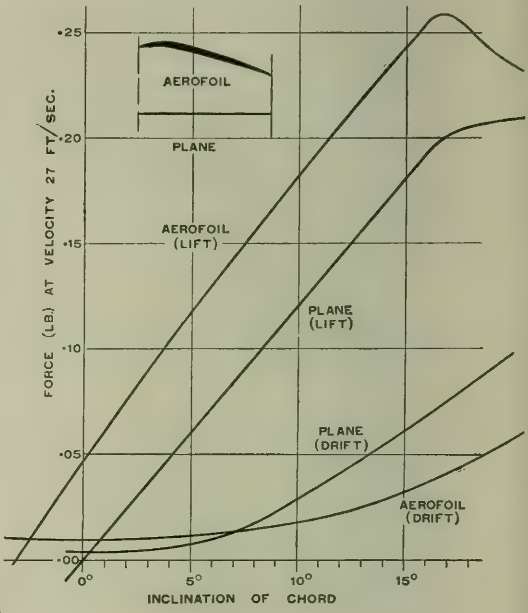


FIG. 7.—*Comparison of Pressure on Flat Plate and on Aerofoil at 12½°.*

FIG. 6.—*Lift and Drift Curves.*



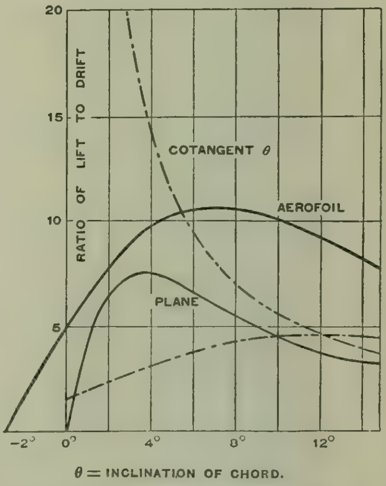


FIG. 8.—*Curves of Lift/Drift.*

known difficulty which experimenters have in determining the precise value of the constant in the pressure-velocity formula for plates, as it is evident that very slight irregularities in the flow of the current will upset the complicated system of eddy formation shown in Fig. 2.

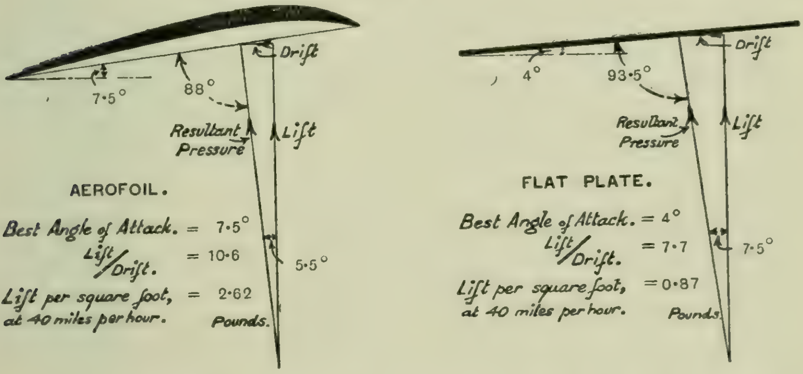
Coming now to the distribution of pressures as the plate becomes less inclined to the current, as shown in Fig. 3, we notice two chief characteristics: (1) that the distribution becomes extremely irregular over the surface of the plate, and (2) that the intensity of the suction effect becomes greater as the inclination becomes less. As might be expected from the method of formation of eddies already spoken of, it is found that at small angles of inclination, especially on the suction side, the intensity of pressure fluctuates between fairly wide limits with extreme rapidity. The points plotted in Fig. 3 represent therefore mean values.

Another characteristic is the remarkable variation in the resultant pressure on a rectangular plate inclined at a given angle to the current, or using the aeronautical term, according to the aspect ratio of the plate, the aspect ratio being defined as the width of the plate divided by its fore and aft dimension. This will be seen from the curves in Fig. 4. It is interesting to note that, in connection with problems on aeroplanes, when the inclination is in the neighbourhood of 10 degrees, the normal pressure per square foot is very considerably greater when the aspect ratio is large than when it is small.

Having referred briefly to the resultant pressure on inclined plates, it is clear that if we propose to use such plates for purposes of flight we must consider how much weight the plate will support at any given inclination and speed, and what will be the force required to propel it at that speed. This we can find by a determination of the components of this resultant pressure in the vertical and horizontal directions, for on the former will depend the total weight the planes will carry, and on the latter will depend the thrust of the propeller. It is usual to call the vertical component the "lift" of the plate and the latter the "drift," or, more generally, the lift is defined as the component of the resultant forces at right angles to the current and the drift as the component parallel to the current, so that the efficiency of the plate for aviation purposes is $\frac{\text{lift}}{\text{drift}}$. To illustrate this, Fig. 5 shows the case of an inclined plate in which, for simplicity, the effect of the friction of the air is neglected, so that the resultant pressure must be normal to the plate. Drawing in the horizontal and normal components of this resultant, it is evident that the ratio of lift to drift is in this case equal to the cotangent of the angle of inclination of the plate to the current. Now let us take an actual case in which the lift and drift are determined by actual measurement of the vertical and horizontal components of the resultant pressure. Fig. 6 shows two sets of curves, one for a flat plate and another for a curved plate, called an aerofoil by Mr. Lanchester. The very marked advantage of the aerofoil over the flat plate is seen at once, for not only is the lift considerably greater at all angles, but above inclinations of 7° the drift is less. This is the reason of the great importance to be attached by designers of aeroplanes to the curved shape of the wing. The reason of this advantage will be apparent from the curves of pressure shown in Fig. 7. It will be seen that although the pressure on the front face is somewhat higher, the main part of the advantage is derived from the increase in intensity of the suction on the back face. It is, however, the curve showing the values of the ratio of lift/drift, and which is derived from the preceding curves, which is the valuable one for designers. Fig. 8 gives this for the three cases of the frictionless plate, the flat plate with friction, and the aerofoil. In this work it is usual to call the angle between the plate, or the chord of the aerofoil, and the current, *the angle of attack.* It will be observed that the most efficient angle of attack for the flat plate is 4°, at which the value of lift/drift is 7·5, and that for the aerofoil is $7\frac{1}{2}$°, at which the lift/drift ratio is 10·6. Further, there is the very marked advantage of the aerofoil in that, as its most efficient angle of attack is considerably larger than that for the plate, its lift at this angle is 2·63 lb. per square foot at 40 m.p.h. against 0·88 lb. per square foot for the flat plate at its most efficient angle.

Another interesting point is that, for angles above $5\frac{1}{2}°$, the aerofoil is more efficient than the flat plate without friction. The reason for this will be apparent from the diagrams in Fig. 9. Thus, drawing in the values of lift and drift experimentally determined, in the case of the flat plate with friction the line of action of the resultant pressure has a component acting from the front to the back of the plate, whereas in the case of the aerofoil the component is from the back to the front, and is thus, as it were, assisting the flight. It will be found that in all cases where the inclination of the resultant to the chord is less than 90° the curve of lift/drift for that plate lies above that for the flat plate without friction.

FIG. 9.


Drift
7·5°
88°
Resultant Pressure
Lift
AEROFOIL.
Best Angle of Attack. = 7·5°
Lift/Drift. = 10·6
5·5°
Lift per square foot, at 40 miles per hour. = 2·62 Pounds.
4°
93·5°
Drift
Resultant Pressure
Lift
FLAT PLATE.
Best Angle of Attack. = 4°
Lift/Drift. = 7·7
7·5°
Lift per square foot, at 40 miles per hour. = 0·87 Pounds.

As an example of the use of these lift/drift curves in design, suppose we wish to find the wing area of an aeroplane moving at forty miles per hour and that we can keep the total weight down to 1,200 lb. Now from our curves we find that at an angle of attack of $7\frac{1}{2}°$ the lift is 0·55 lb. per square foot at 27 feet per second, so that at 59 feet per second the lift would be 2·63 lb. per square foot, and hence the area of planes required would be 458 square feet.

Propellers.—Having realized the importance, from the point of view of the design of the wings, of a correct knowledge of the values of the lift and drift ratio for aerofoils of various forms, attention may be drawn to another valuable application of this kind of experimental knowledge in the design of the propelling mechanism, that is, the design of the propeller itself. To illustrate this, it is necessary to refer to that method of propeller design which is usually called the constant incidence method, and which is due to Mr. Drzwiecki, of Paris.

Shortly stated, M. Drzwiecki's method of propeller design amounts to this. Given the speed of the aeroplane or airship, and the number of revolutions of the engine, we set out a propeller of a suitable section of blade and diameter so that the pressure-face of the blades lies on a helicoid whose pitch is the distance advanced by the air-ship per revolution of the engine. Evidently this propeller fitted to an air-ship moving at the desired speed would give no thrust at all, that is, the motion of the air would be tangential to the working faces of the blades. If, however, we twist the whole blade about an axis perpendicular to the axis of rotation through a small angle, then each element of the blade will become, when the ship is in motion, a small

FIG. 10.—*Drzwiecki's Method of Propeller Design.*

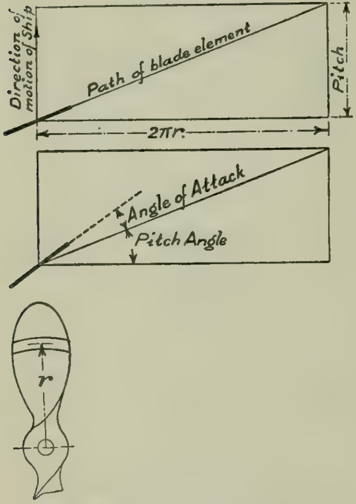
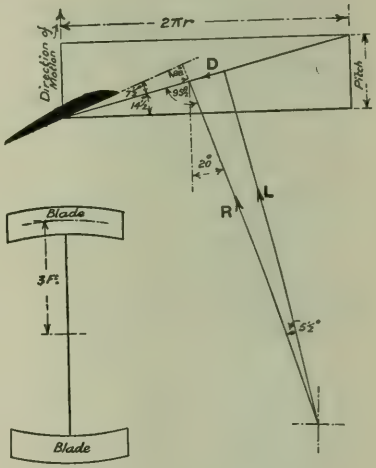


FIG. 11.



aerofoil with an angle of attack which is the same for all the elements and equal to the small angle through which the blade was turned. Fig. 10 is an illustration of this method. Now, if we knew from experiments in our wind channel the resultant pressure in magnitude and direction on such an aerofoil, or, in other words, its lift and drift at this angle of attack, we could predict the thrust per square foot of blade in the direction of motion, and hence, from the known or calculated resistance to flight of the aeroplane, we can find the blade area required, and so complete the design of the propeller. Further, if the blade of our propeller consisted of a narrow slip of metal such as that shown in Fig. 11, in which the velocity of all the points does not vary considerably from the mean, such an experiment in the wind channel would be possible, but, unfortunately, that is not the case. The blade of an efficient propeller in practice extends from the tip to the boss, so that the velocity of its points varies widely. There remains the possibility of dividing the blade into elementary areas and applying the treatment I have sketched, and this is generally done by the use of some graphic method of integration; but you will realize the difficulty, which is, that it is quite impossible to determine with any accuracy the pressure on any elementary strip of a blade by an experiment on a model of that strip because the pressure on it is dependent largely on the surrounding material. Having pointed out the difficulty, I think it would be of interest to put before you an elementary calculation of horse-power and propeller surface, on the assumption that the whole surface of the propeller is concentrated in two strips at a mean radius r from the axis of the shaft. If this method is followed, the application to the real case is comparatively easy.

The case we took in considering wing surface was an aeroplane of total weight 1,200 lb. moving at forty miles per hour. First, to estimate the total force required to propel it at this speed, we know that since the lift/drift ratio is 10·6 the resistance of the plane is 113 lb. Assume that the resistance of the wires and struts is 50 lb. and that of the hull is 80 lb., so that the total force required is 243 lb. Now, making the assumption as to form of blades which I have mentioned, and adopting Drzwiecki's method of design, let us take the case of the aerofoil already described and apply it to the design of the propeller. The diagram in Fig. 11 shows the arrangement. Taking a mean radius of 3 feet and the revolutions of the shaft as 720 per minute, the pitch at 40 miles per hour is 4·9 feet and the pitch angle is 14½°.

The angle of attack as before is 7½°, and at that angle the lift of the aerofoil whose section is shown was 0·55 lb. per square foot at 27 feet per second. The lift/drift ratio at that angle is 10·6, so that the corresponding drift is 0·05 lb. per square foot, and the resultant force is therefore 0·552 lb. per square foot inclined at an angle of 88° to the chord of the aerofoil, or 95½ to the path as shown. Now, the velocity of the blade in its path is 226 feet per second, so that the resultant force per square foot at that speed is 38·5 lb. per square foot. The effective thrust on the strip in its direction of motion is $38 \cdot 5 \cos 20° = 36 \cdot 2$. Therefore the total blade area required is $\frac{243}{36 \cdot 2} = 6 \cdot 7$ square feet or 3·35 square feet per blade.

This then settles the area of the propeller blades. We can also find the horse-power required, for the torque to produce this thrust is evidently

$$36 \cdot 2 \cos 70° \times 3 \text{ feet} \times 6 \cdot 7 \text{ sq. feet} = 265 \text{ foot-lb.}$$

so that the B.H.P. required is given by

$$\text{B.H.P} \times 550 = 2\,\pi\, 265 \times 12,$$

or, $$\text{B.H.P.} = 36 \cdot 3.$$

The Lecture is illustrated by 11 Figs. in the letterpress.

The Institution of Mechanical Engineers.

PROCEEDINGS.

February 1912.

The Sixty-Fifth Annual General Meeting was held at the Institution on Friday, 16th February 1912, at Eight o'clock p.m.; Sir H. Frederick Donaldson, K.C.B., Vice-President, in the Chair.

The Chairman, before proceeding with the business of the Meeting, asked for the sympathy of the members with their President in the disappointment which rested upon him that evening in that he had been prevented from attending the Meeting owing to ill-health. Those who had watched the care and attention which Mr. Ellington had given to everything pertaining to the interests of the Institution would realize what a real grief and disappointment his absence from the Meeting must be to him, especially as the members would shortly hear that they had again elected him President for a second year of office. He intimated that his own occupation of the Chair was due to the action of his colleagues on the Council.

The Minutes of the previous Meeting were read and confirmed.

The Chairman announced that the following three Transferences had been made by the Council :—

Associate Members to Members.

Backhouse, John,	Liverpool.
Britten, Thomas,	Wolverhampton.
Mills, Joseph Amos,	Tarquah, W. Africa.

The Chairman presented the prizes awarded by the Council for the best two Papers in the Graduates' Section read during the Session 1910–11—to Mr. A. J. Bremner for his Paper on "Balancing of Engines," and to Mr. C. A. Collins for his Paper on "Manufacture of Interchangeable Parts."

The Chairman reported that the Ballot Lists for the election of Officers for the present year had been opened by a Committee of the Council, and that the following were found to be duly elected :—

President.

Edward B. Ellington,	London.

Vice-Presidents.

The Right Hon. Lord Merthyr, K.C.V.O.,	Aberdare.
Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.

Members of Council.

Archibald Barr, D.Sc.,	Glasgow.
George J. Churchward,	Swindon.
The Right Hon. Lord Pirrie, K.P., P.C., LL.D.,	Belfast.
Walter Pitt,	Bath.
Mark Robinson,	London.
Wilson Worsdell,	Ascot.

The Council for the present year is therefore as follows: —

President.

Edward B. Ellington,	London.

Past-Presidents.

John A. F. Aspinall,	Manchester.
Sir Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
William H. Maw, LL.D.,	London.
E. Windsor Richards,	Caerleon.
Percy G. B. Westmacott,	Ascot.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

Vice-Presidents.

Henry Davey,	Ewell.
Sir H. Frederick Donaldson, K.C.B.,	Woolwich.
Michael Longridge,	Manchester.
The Right Hon. Lord Merthyr, K.C.V.O.,	Aberdare.
A. T. Tannett-Walker,	Leeds.
Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.

Members of Council.

William H. Allen,	Bedford.
Archibald Barr, D.Sc.,	Glasgow.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S.,	London.
George J. Churchward,	Swindon.
Dugald Clerk, F.R.S.,	London.
Sir Robert A. Hadfield, D.Met., F.R.S.,	Sheffield.
H. S. Hele-Shaw, LL.D., F.R.S.,	London.
Edward Hopkinson, D.Sc.,	Manchester.
J. Rossiter Hoyle,	Sheffield.
George Hughes,	Horwich.
Henry A. Ivatt,	Hayward's Heath.
Henry Lea,	Birmingham.
Robert Matthews,	Manchester.

Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B.,	London.
The Right Hon. Lord PIRRIE, K.P., P.C., LL.D.,	Belfast.
WALTER PITT,	Bath.
THOMAS P. REAY,	Leeds.
MARK H. ROBINSON,	London.
Captain H. RIALL SANKEY, R.E. ret.,	London.
WILSON WORSDELL,	Ascot.

(*One Vacancy to be filled up in March.*)

The CHAIRMAN reminded the members that at the present Meeting the appointment had to be made of an Auditor for the current year.

Mr. J. W. SUTTON moved: "That Mr. Robert A. McLean, F.C.A., of 1 Queen Victoria Street, London, E.C., be reappointed to audit the accounts of the Institution for the present year, at the same remuneration as last year, namely, Fifty guineas."

Mr. GEORGE W. THOMPSON seconded the motion, which was carried unanimously.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF THE COUNCIL

FOR THE YEAR 1911.

The Council have pleasure in presenting to the members the following Report of the progress and work of the Institution during the past year.

His Majesty the King has conferred honours upon the following members of the Institution :—Sir William T. Lewis, Bart., K.C.V.O., has been created a Baron (Lord Merthyr); a Knight Commandership of the Order of the Bath has been conferred on Mr. H. F. Donaldson, C.B., and on Dr. J. A. Ewing, C.B.; a Knight Commandership of the Most Eminent Order of the Indian Empire on the Hon. Francis J. E. Spring, C.I.E.; a Knighthood on Mr. G. Croydon Marks, M.P.; a Companionship of the Royal Victorian Order on Mr. J. Scott Pitkeathly; a Companionship of the Order of the Bath on Mr. F. Dudley Docker; and Membership of the Royal Victorian Order on Rai Bahadur Ganga Ram, C.I.E., and Captain George H. Willis, R.E.

On the occasion of the Coronation of His Majesty King George V., *Honorary Life Member*, the Council presented an Illuminated Address of Congratulation,* which was duly acknowledged on behalf of His Majesty.

The American Society of Mechanical Engineers have presented to the Institution a handsomely-framed Illuminated Address † referring in a very gratifying manner to the pleasure experienced by their members who took part in the Joint Meeting held in

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* Proceedings, 1911, Plate 22.

† *Ibid*, Plate 58.

Birmingham and London in the Summer of 1910. The Council of the American Society in September elected as an Honorary Member, Mr. John A. F. Aspinall, who was President of the Institution during the Joint Meeting.

The changes which have taken place in the roll during 1911 are shown in the following tabulated statement:—

	Hon. M.	M.	A.M.	A.	G.	Totals.	
Totals at 31st December 1910	6	2,521	2,419	61	693		5,700
Elected	1	70	276	1	131		
Reinstated	—	—	—	—	—		
Transferred	—	63	—	—	—		
Total additions during 1911	1	133	276	1	131	542	
Deceased		57	11	4	2		
Resigned	—	31	25	2	24		
Erased	—	16	62	—	17		
Graduates elected Associate Members	—	—	—	—	54		
Graduates retired under By-law 3	—	—	—	—	42		
Elections voided	—	—	2	—	2		
Transferred	—	—	62	—	1		
Total deductions during 1911	—	104	162	6	142	414	128
Totals at 31st December 1911	7	2,550	2,533	56	682		5,828

The following Deceases of members of the Institution were reported during the year:—

1891. Ahrbecker, Henry V.C. (*Deceased* 1910)
1859. Airedale, The Right Hon. Lord, P.C.
1908. Anderson, James (*A.M.*)
1899. Appleby, George W. (*Deceased* 1910)
1895. Ashcroft, Andrew George
1902. Ashton, Harold T., D.Sc. (*Deceased* 1910)
1889. Atkinson, Alexander (*Deceased* 1910)
1869. Bainbridge, Emerson
1905. Barrett, Harry (*A.M.*) (*Deceased* 1910)
1902. Beirne, Sidney A. (*A.M.*)
1885. Bicknell, Arthur C.
1895. Britten, Thomas J. (*Deceased* 1910)
1887. Cochrane, George

1899. Crofts, John C. T.
1905. Croll, James (*Deceased* 1910)
1875. Crossley, Sir William J., Bart.
1904. Davidson, William (*Deceased* 1910)
1888. Gaze, Edward H. J.
1884. Gimson, Arthur J.
1901. Greenhill, Thomas A.
1880. Hallett, J. Harry
1869. Harfield, William H. (*Deceased* 1910)
1903. Heald, James A.
1911. Heap, William (Colombo)
1902. Hincks, John M. (*A.M.*)
1904. Howlden, Edwin F.
1891. Hubback, Charles A.
1900. Iddon, James
1892. Jenkins, William J.
1895. King, T. Scott
1902. Kitching, Alfred
1908. Koziell, Eng. Captain J. P., I.R.N.
1907. Landstein, Wilfred (*A.M.*)
1898. McCowen, Victor A. H. (*Deceased* 1910)
1901. McGregor, James (*A.M.*)
1891. Middleton, Robert T.
1900. Morgan, Charles H.
1890. Morris, F. Sanders
1909. Nisbet, J. Wylie
1868. Norris, William G.
1904. Reynolds, James
1874. Riches, T. Hurry (*Past-President*)
1905. Rowe, Patrick (*A.M.*)
1903. Salter, John R. (*A.M.*) (*Deceased* 1910)
1887. Scott, Sir Walter, Bart. (*A.*) (*Deceased* 1910)
1882. Selfe, Norman
1876. Taunton, Richard H.
1896. Taylor, William I.
1902. Taylor, William R. C. (*A.M.*)
1902. Tunley, Percy J. (*A.M.*)
1904. Turnbull, William L.
1881. Wake, Henry H.
1865. Walpole, Thomas
1903. Watson, John
1877. Watts, John
1906. Webster, Frank T. (*A.M.*)
1887. Winmill, George (*Deceased* 191
1909. Wright, William R.

Of these Mr. Riches was elected a Member of Council in 1885, a Vice-President in 1899, and President in 1907–08.

The Accounts for the year ended 31st December 1911 are submitted (*see* pages 96 to 101), having been duly certified by Mr. Robert A. McLean, F.C.A., the Auditor appointed by the members at the last Annual General Meeting.

The total revenue for the year 1911 was £15,922 11*s.* 9*d.*, while the expenditure was £12,295 6*s.* 6*d.*, leaving a balance of revenue over expenditure of £3,123 5*s.* 3*d.*, exclusive of Entrance Fees £454 and Life Composition £50 carried direct to Capital Account. In accordance with the Resolution passed at the Special General Meeting on 14th July, the Council arranged for a new issue of 4% Debentures, in order to meet the expense of the extension of the Institution Building. Of this issue there has been allotted a total of £34,025, made up of £20,625 new subscriptions and £13,400 exchanged for a similar amount of the 1897 issue. The outstanding Debentures (£6,600) of the 1897 issue were redeemed on 1st January 1912.

The financial position of the Institution at the end of the year is shown by the balance sheet. The total investments and other assets amount to £108,896 6*s.* 7*d.*; and, deducting therefrom the outstanding old Debentures, £13,400 exchanged for new issue, and the amount of £17,610 received on account of the new issue, and other liabilities, including the sum set aside for the Leasehold and Debenture Redemption Fund, the capital of the Institution amounts to £60,631 13*s.* 0*d.* The certificates of the securities have been duly audited by the Finance Committee and the Auditor.

Progress has been made with the extension of the Institution premises facing Princes Street. The tenancy of Storey's Gate Tavern was terminated at Christmas, and building leases have been arranged with the Ecclesiastical Commissioners and Dr. Williams' Trustees, the ground landlords of the Princes Street site. Of the four competitive designs exhibited at the General Meeting in March, that by Mr. James Miller, F.R.I.B.A., A.R.S.A., of Glasgow, was selected. The building line to Princes Street has been straightened, provision being made for widening the street to 41 feet. Estimates were obtained from leading building firms in London, and the contract has been let to Messrs. John Mowlem and Co., Ltd. It is hoped that the extension may be completed in the early part of 1913.

In order to give practical effect to the suggestions made in past years, Mr. William H. Allen, *Member of Council*, has offered one thousand £1 shares in Messrs. William H. Allen, Son and Co., Ltd., to found a Benevolent Fund for members of the Institution or their dependents. The Council have very cordially thanked Mr. Allen for this munificent offer, and are arranging for a Benevolent Fund to be established under the Companies' Consolidation Act 1908, as a company limited by guarantee. The draft Memorandum and Articles of Association are now before the Board of Trade for approval.

Mr. Ellington in his Presidential Address * referred to the qualifications which should be possessed by Mechanical Engineers; and the Council have had under consideration for a considerable time the question of entrance examinations for the younger applicants for admission to the Institution. The Council are of opinion that the time has come for instituting such an examination, and their suggestions are contained in an Appendix (page 124), which is followed by a Note on the subject by the President, with a view to the full discussion of the matter at the Annual General Meeting. Before any further action is taken, the Council desire to have the question thoroughly ventilated, and to be sure that the great majority of the members approve the proposals.

The work on the Aluminium-Zinc alloys at the National Physical Laboratory, referred to in the last Annual Report, has been completed, and a Report will be presented shortly; this will include some results of special interest which have been obtained in the preliminary work on the ternary alloys.

Professor F. W. Burstall's Report on a new series of Gas-Engine Tests, varying only the ratio of air to gas and the composition of the charge during expansion, is on the point of completion.

Papers are being prepared for discussion dealing with "Refrigeration" and "The Action of Steam passing through Nozzles and Steam Turbines," subjects which are deemed suitable for Research.

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* Proceedings, 1911, page 220.

The Institution during the year has been represented on the following organizations:—

Universities of Bristol, Liverpool, and Sheffield.
Imperial College of Science and Technology.
National Physical Laboratory.
Engineering Standards Committee.
School of Metalliferous Mining (Cornwall).
Imperial Education Conference, London, April 1911.
International Congress of the Applications of Electricity, Turin, September 1911.
Conference of the Smoke Abatement League of Great Britain, Manchester, November 1911.
International Smoke Abatement Exhibition, London, May 1912.
Optical Convention, London, 1912.
International Road Congress, London, June 1913.

Applications have been granted from time to time for the following kindred Societies to hold Meetings in the Institution House:—

Institution of Naval Architects.
Institution of Gas Engineers.
Institution of Mining and Metallurgy.
Institution of Heating and Ventilating Engineers.
British Foundrymen's Association.
Institution of Automobile Engineers.
Institute of Metals.

The Council desire to thank those members and others who have made presentations to the Library. A complete list of additions will be found on pages 105–123. For some years past a considerable number of members have made use of the facilities for searches in the Library, to which attention has been drawn in several recent Annual Reports. During the year 516 books were loaned to members, and 108 searches for special information were made by the staff on behalf of members. Progress has been made with the new card-catalogue of books and pamphlets.

Towards the end of 1910 a petition was received from a number of members, urging the publication by the Institution of abstracts of articles of particular importance to Mechanical

Engineers which appear in the technical literature of the world. After obtaining a variety of estimates for dealing with the periodical literature, and considering the possibility of co-operation with other Societies, the Council resolved to ascertain the opinion of the members generally by means of a reply-circular, the result of which is that, up to 16th February 1912, 761 members were in favour of the proposal, and 328 against. Various suggestions have also been made, and the whole question will be further considered.

The Summer Meeting was held in Zürich and Northern Switzerland, 24th–31st July, and was most successful from the point of view both of the Papers read and of the engineering interest of the works visited. The Council desire to express their obligations to Colonel P. E. Huber, Colonel Gustave L. Naville, Professor Dr. A. Stodola, Mr. Eduard Sulzer-Ziegler, Mr. Jacob Sulzer-Imhoof, *Member*, Professor Dr. W. Wyssling and other Swiss Engineers for the assistance rendered in the preparations. At a subsequent Meeting the Council formally nominated Dr. Stodola as an Honorary Life Member of the Institution. The Meetings were held in the Aula of the Swiss Polytechnikum and the Institution Dinner in the Tonhalle, Zürich. Visits were made to the more important workships and hydraulic power-stations in Northern Switzerland. The attendance at the Meeting was 153 Members and Graduates, 44 Visitors and 65 Ladies, in addition to Swiss friends.

Monthly Meetings were held throughout the year with the exception of May, June, August, and September. These Meetings were occupied with the reading and discussion of the following Papers:—

Modern Electrical Dock-Equipment, with special reference to Electrically-operated Coal Hoists; by Mr. Walter Dixon, *Member*, and Mr. George H. Baxter, *Member*.

Address by the President, Mr. Edward B. Ellington.

Gas-Producers; by Mr. J. Emerson Dowson, *Member*.

The Effect of varying proportions of Air and Steam on a Gas-Producer; by Mr. E. A. Allcut, *Graduate*.

Electric Traction in Switzerland; by Mr. E. Huber-Stockar.

Rack-Railway Locomotives of the Swiss Mountain Railways; by Mr. J. Weber and Mr. S. Abt.

Modern Diesel Oil-Engines; by Mr. J. F. Schubeler.

Some new types of Dynamometers; by Dr. Alfred Amsler.

High-Pressure Water-Power Works; by Mr. L. Zodel.

Results of Experiments with Francis Turbines and Tangential (Pelton) Turbines; by Professor Dr. Franz Prášil.

Steam-Turbines; by Mr. H. Zoelly.

The Endurance of Metals: Experiments on Rotating Beams at University College, London; by Mr. E. M. Eden, Mr. W. N. Rose, and Mr. F. L. Cunningham, *Graduate.*

Double-cutting and High-speed Planing Machines; by Mr. J. Hartley Wicksteed, *Past-President.*

Oil-burning Locomotives on the Tehuantepec National Railroad, Mexico; by Mr. R. Godfrey Aston, *Graduate.*

The following Papers were accepted for publication in the Proceedings:—

The Energy-Diagram for Gas; by Professor F. W. Burstall, *Member.*

Notes on Bronze Pumps in the British Museum; by Mr. James P. Maginnis, *Member.*

A Lecture describing the Turbines, Condensers, Blowers, etc., exhibited at the Works of Messrs. Brown, Boveri and Co., Baden, Switzerland; by Mr. Eric Brown.

Arising out of the Discussion on the Constitution of Troostite and the Tempering of Steel,* the Council arranged for the delivery in April by Dr. Walter Rosenhain of two Lectures on Steel dealing with the Relations of Carbon and Iron, including the limitations and effects of the varying constituents. These Lectures, of which a fully illustrated report has been published in the Proceedings,† were much appreciated by the members.

The Calcutta and District Section of the Institution have continued their Meetings during the year. Advance copies of the

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* Proceedings, 1910, page 1661.

† Proceedings, 1911, page 241.

Papers read in London have been sent to India for their use, and the following local Papers have been read:—

The Evolution of Valves and Safety Appliances for Boilers; by Mr. H. M. Andrew (*printed*). (January.)

Description of His Majesty's Mint, Calcutta; by Mr. A. Dryden, *Member* (*printed*). (January.)

The Burning of Fuel by the Underfeed System of Firing; by Mr. B. W. Bagshawe, *Associate Member* (*printed*). (February.)

The Curtis Steam-Turbine, with special reference to the Utilization of Exhaust Steam; by Mr. C. McCarthy-Jones, *Associate Member* (*printed*). (March.)

A Visit was made to His Majesty's Mint, Calcutta.

A grant of £25 has been made from the Institution funds towards the expenses of the Section. Sixty-four members of the Institution belong to the Section, of whom Mr. J. Wyness, *Associate*, has acted as Chairman during the Session 1910–11, and Mr. A. Dryden, *Member*, is the Honorary Secretary and Treasurer.

The Graduates held monthly Meetings during the Session 1910–11. Nine Visits were made to works. The average attendances of Graduates were 27 at the Meetings and 14 at the Visits. The following Papers were read and discussed:—

Recent Improvements in Wood-working Machinery; by Mr. A. E. Harris.

Foundry Plant, Machinery and Working; by Mr. E. Timothy.

Requirements of Illumination and the Status of Gas Lighting; by Mr. J. C. Briggs.

Air Movers; by Mr. G. L. Copping.

The Balancing of Engines; by Mr. A. J. Bremner.

The Manufacture of Interchangeable Parts; by Mr. C. A. Collins.

The Application of Liquid Fuel to the Industries; by Mr. O. Wickham.

Prizes for the best Papers have been awarded by the Council to Mr. Bremner and Mr. Collins.

At the February Meeting, Captain H. Riall Sankey, *Member of Council*, delivered an illustrated Lecture on "Wireless Telegraphy," which has been printed and circulated amongst the Graduates.

Those Graduates residing beyond the reach of the London Meetings have welcomed invitations to attend local Meetings and

Debates extended to them by the Engineering Societies of the Universities of Birmingham, Bristol, Edinburgh, Glasgow, Liverpool, and Manchester, and of Armstrong College, Newcastle-upon-Tyne. The Council gratefully acknowledge this continuation of the invitations of previous years.

It is intended to hold the next Summer Meeting in Belfast.

Mr. Arthur Keen, the Senior Vice-President, in view of the fact that he does not now make journeys to London and cannot therefore attend the Council Meetings, has decided not to offer himself for re-election. The Council, in acknowledgment of his services to the Institution, have passed the following resolution :—

> "That a special Vote of Thanks be conveyed to Mr. Arthur Keen, on his retirement from the Council of the Institution of Mechanical Engineers, in recognition of his long and valuable services, he having been elected a Member of Council in 1891 and having acted as Vice-President since 1898; and that this Resolution be entered upon the Minutes."

To fill the vacancy thus created, the Council have nominated for election as a Vice-President, Professor W. Cawthorne Unwin, LL.D., F.R.S.

The result of the Ballot for the election of President, two Vice-Presidents, and six Members of Council, to fill vacancies caused by retirement, will be announced at the Annual General Meeting.

ACCOUNT OF REVENUE AND EXPENDITURE

AND

BALANCE SHEET FOR 1911.

Dr. ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£	s.	d.	£	s.	d.
To Expenses of Maintenance and Management—						
Salaries and Wages	3,548	12	8			
Postages, Telegrams, and Telephone	708	1	1			
Heating, Lighting, and Power	100	16	10			
Fittings and Repairs	21	5	1			
Housekeeping	119	17	5			
Incidental Expenses	69	0	4			
				4,567	13	5
,, Printing, Stationery, and Binding—						
Printing and Engraving Proceedings	1,729	17	0			
Stationery and General Printing	825	8	5			
Binding	44	6	7			
				2,599	12	0
,, Rent, Rates, Taxes, &c.—						
Ground Rent (Institution)	875	17	2			
Do. No. 5 Princes Street	135	0	0			
Do. Storey's Gate Tavern	100	0	0			
Rates and Taxes	880	5	1			
Insurance	32	12	9			
				2,023	15	0
,, Meeting Expenses—						
Printing and Translations	459	18	3			
Travelling and Incidental Expenses	275	2	10			
Reporting	51	2	3			
				786	3	4
,, Conversazione				249	10	11
,, Dinner Expenses				101	8	4
,, Calcutta and District Section				25	0	0
,, Graduates' Prizes				9	19	8
,, Card-Catalogue of the Library				100	0	0
,, Books purchased				66	12	6
,, Debenture Expenses				65	13	5
,, Certificate of Membership				54	0	0
,, Coronation Illuminations				23	16	9
,, Expenses in connection with Research Committees				199	2	0
,, Interest on Bank Loan				59	19	9
,, Provision for accounts unrendered (estimated)				400	0	0
,, Depreciation on Furniture and Fittings				115	5	10
,, Debenture Interest (less Bank Interest on New Deb. acct.)				847	13	7
Total Expenditure				12,295	6	6
,, Entrance Fees, carried to Capital Account (*per contra*)				454	0	0
,, Life Compositions, carried to Capital Account (*per contra*)				50	0	0
,, Balance, being excess of Revenue over Expenditure (exclusive of value of Subscriptions in arrear), carried to Balance Sheet				3,123	5	3
				£15,922	11	9

FOR THE YEAR ENDED 31st DECEMBER 1911. *Cr.*

Revenue.

	£	s.	d.	£	s.	d.
By Subscriptions for 1911				13,222	0	0
„ Subscriptions in arrear, paid in 1911				910	0	0
„ Entrance Fees for 1911				454	0	0
„ Life Compositions				50	0	0
„ Rent of Upper Floor of Institution Building	428	2	6			
Do. Storey's Gate Tavern	316	14	0			
Income Tax (1910) refunded	14	6	5			
				759	2	11
„ Interest, &c. (exclusive of Trust Funds)— *From Investments and Deposits at Bank*				297	7	0
„ Reports of Proceedings— *Extra Copies sold*				229	19	4
„ Debenture Transfer Fee				0	2	6
				£15,922	11	9

Dr. **BALANCE SHEET**

	£ s. d.	£ s. d.	£ s. d.
To Debentures (1897 Issue)		25,000 0 0	
Less Debentures redeemed during 1908 *and* 1909	5,000 0 0		
Less Debentures exchanged, or to be exchanged, for New Issue	13,400 0 0	18,400 0 0	
			6,600 0 0
,, New 4% Debentures (1912 Issue), £34,025 allotted as follows:—			
134 *Debentures of* £100 *each exchanged, or to be exchanged, for* 1897 *Issue*			13,400 0 0
193 *Debentures of* £100 *each subscribed*	19,300 0 0		
23 *Debentures of* £50 *each subscribed*	1,150 0 0		
7 *Debentures of* £25 *each subscribed*	175 0 0		
		20,625 0 0	
Total receipts on account of New Issue at 31st December 1911			17,610 0 0
,, Sundry Creditors—			
Accounts owing at 31st *Dec.* 1911		1,477 15 6	
Provision for accounts unrendered (estimated)		400 0 0	
Interest on New Debentures instalments		74 19 5	
Unclaimed Debenture Interest (coupons not presented)		20 16 9	
			1,973 11 8
,, Subscriptions paid in advance			169 10 0
,, Trust Funds (see pages 100–1), *per contra*—			
Willans Premium Fund		174 15 8	
Water Arbitration Prize Fund		553 11 9	
Bryan Donkin Fund		378 16 7	
Starley Premium Fund		451 3 0	
			1,558 7 0
,, Sinking Fund set aside for Redemption of Debentures and Institution's Leasehold Property			6,953 4 11
,, Balance, being Capital of the Institution, exclusive of the Sinking Fund:—			
Balance at 31st *Dec.* 1910		57,004 7 9	
Add—			
Excess of Revenue over Expenditure for the year ended 31st *Dec.* 1911		3,123 5 3	
Amount received from Entrance Fees during 1911		454 0 0	
Amount received from Life Compositions during 1911		50 0 0	
			60,631 13 0
			£108,896 6 7

Signed by the following Members of the Finance Committee :—

E. B. ELLINGTON. | H. F. DONALDSON (*Chairman*).
W. H. MAW. | H. S. HELE-SHAW.
H. RIALL SANKEY.

AT 31ST DECEMBER 1911. *Cr.*

	£	s.	d.	£	s.	d.
By Cash (exclusive of Trust Funds)—						
In Union of London and Smiths Bank—						
Deposited at Interest	16,210	0	0			
On Current Account	331	5	0			
,, Sinking Fund Account	156	5	3			
	16,697	10	3			
In the Secretary's hands	166	0	8			
				16,863	10	11
,, Amount in Union of London and Smiths Bank to meet unclaimed Debenture Interest (*coupons not presented*)				20	16	9
,, Investments (*of which* £6,953 4*s.* 11*d. has been set aside for Redemption of Debentures and the Institution's Leasehold Property*) *Cost*				14,956	9	6
L. and N. W. Ry. 3% *Debenture Stock.*	5,408	0	0			
Midland Ry. 2½% *Debenture Stock.*	5,080	12	0			
Metropolitan Water (*B*) 3% *Stock.*	2,781	10	8			
2½% *Consols.*	2,709	3	4			
London County 3½% *Consolidated Stock.*	1,189	0	0			
L. & S. W. Ry. 3% *Consolidated Deb. Stock.*	674	0	0			
The Market Value of these investments at 31st *Dec.* 1911 *was about* £14,148.						
,, Subscriptions in arrear, *not valued.*						
,, Furniture and Fittings (*less depreciation*)				1,037	13	3
,, Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)				1,340	0	0
,, Proceedings—stock of back numbers, *not valued.*						
,, Institution House *Cost*	60,270	2	10			
,, Princes Street Extension	12,849	6	4			
				73,119	9	2
,, Investments and Cash in Bank on account of Trust Funds (see pages 100–1), *per contra*—						
Willans Premium Fund	174	15	8			
Water Arbitration Prize Fund	553	11	9			
Bryan Donkin Fund	378	16	7			
Starley Premium Fund	451	3	0			
				1,558	7	0
				£108,896	6	7

I have examined the above Balance Sheet and report that I have obtained all the information and explanations I have required. In my opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of the information and explanations given to me and as shown by the Books of the Institution.

ROBERT A. MCLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

23*rd January* 1912.

WILLANS PREMIUM FUND.

(Under a Joint Trust with the Institution of Electrical Engineers.)

Investment £159 8*s*. 5*d*. of India 3% Stock . . . . cost £165 5*s*. 0*d*.

Dr.	£ *s.* *d.*		*Cr.* £ *s.* *d.*
To Balance, held in trust .	9 10 8	By Balance from 1910 . .	4 15 4
		,, Interest, 1911 . . .	4 15 4
	£9 10 8	(*No Income Tax deducted.*)	£9 10 8

See Balance Sheet.

(Declaration of Trust, *see* Proceedings 1907, page 23.)

WATER ARBITRATION PRIZE FUND.

Investment £523 10*s*. 2*d*. of Metropolitan Water (B) 3% Stock cost £500 0 0

Dr.	£ *s.* *d.*		*Cr.* £ *s.* *d.*
To Balance	53 11 9	By Balance from 1910 .	38 15 11
		,, Interest, 1911 . . .	14 15 10
	£53 11 9		£53 11 9

See Balance Sheet.

(Regulations, *see* page 102.)

BRYAN DONKIN FUND.

Investment £349 15*s.* 8*d.* of London County 3½% Consolidated Stock
cost £360 6*s.* 6*d.*

Dr.							*Cr.*
	£	*s.*	*d.*		£	*s.*	*d.*
To Balance	18	10	1	By Balance from 1910 .	6	19	9
				„ Interest, 1911 . . .	11	10	4
	£18	10	1		£18	10	1

See Balance Sheet.

(Regulations, *see* page 103.)

STARLEY PREMIUM FUND.

Investment £435 8*s.* 5*d.* of London County 3½% Consolidated Stock
cost £440 7*s.* 6*d.*

Dr.							*Cr.*
	£	*s.*	*d.*		£	*s.*	*d.*
To Award to Mr. L. A.				By Balance from 1910 .	37	8	8
Legros . . .	41	0	6	„ Interest, 1911 . . .	14	7	4
„ Balance	10	15	6				
	£51	16	0		£51	16	0

See Balance Sheet.

(Regulations, *see* page 104.)

The usual Claim for refundment of Income Tax has been made.

WATER ARBITRATION PRIZE.

REGULATIONS FOR THE THIRD AWARD TO BE MADE IN FEBRUARY 1913.

1. The Award will be made for the best original Paper dealing with NEW INVESTIGATIONS OF HYDRAULICS, OR RECENT DEVELOPMENTS IN THE APPLICATION OF WATER POWER, accepted by the Council for publication with or without discussion in the Institution Proceedings of 1911 and 1912, provided that the Paper be of sufficient merit in the judgment of the Council.

2. Papers should be sent in as soon as possible, but not later than 1st September 1912.

3. Papers should be illustrated by scale drawings, but may be accompanied by photographs, lantern-slides, and specimens.

4. Any Paper not accepted for printing in the Proceedings will be returned to the author.

5 The Prize will have the value of about £30, and will be accompanied by a certificate bearing the seal of the Institution.

WILLANS PREMIUM.

The next Award will be made in February 1913 for the best Paper, published in the Proceedings 1907–12, inclusive, dealing with such a general subject as the utilization or transformation of energy, treated especially from the point of view of efficiency or economy. (For Declaration of Trust, *see* Proceedings 1907, page 23.)

Bryan Donkin Fund.

Second Award, February 1913.

1. The Bryan Donkin Award, consisting of the interest on the sum of £360 6*s.* 6*d.*, shall be made triennially, beginning in 1910.

2. The grant or grants made at each Award shall be devoted to assisting original research.

3. Every three years the Council shall direct attention to the Bryan Donkin Fund, and shall announce that on a convenient date, to be fixed by them, they will be open to receive from those engaged in original research in Mechanical Engineering applications for grants in aid.

4. All applications so received shall be considered by a Committee specially appointed by the Council for that purpose, who shall make recommendations to the Council upon the apportionment of the sum available. If this Committee shall consider that none of the applications is deserving of a grant, or that the sum available is in excess of the grants which it is desirable to make, they shall so report to the Council.

5. In the event of no grant being made or the grants made amounting to less than the sum available, the surplus shall be devoted to aiding the Research Committees of the Institution and shall be distributed in such proportions as the Council shall decide.

STARLEY PREMIUM FUND.

Regulations.

Second Award, February 1914.

1. The name of the Fund shall be the Starley Premium Fund.

2. The amount of the Fund (about £440) shall be invested in the name of the Institution of Mechanical Engineers in a trustee security, with power to vary.

3. The income derived from the Fund, after payment of any expenses incidental to the administration of the Fund, shall be presented triennially in and after February 1911 for the best original Paper dealing with "THE DEVELOPMENT OF ROAD LOCOMOTION" published in the Proceedings of the Institution of Mechanical Engineers during the previous three years: it being understood that the premium shall not be awarded unless a Paper of sufficient merit in the judgment of the Council shall have been so published since the preceding Award.

4. In the event of no Award at the end of any triennial period the premium available for that Award shall be added to the capital of the Fund, unless during the ensuing triennial period two Papers of sufficient merit and dealing with "The Development of Road Locomotion" be communicated, in which event the Council may, if they think fit, present two premiums.

5. The premium shall be awarded in any form which the Council may from time to time determine.

LIST OF ADDITIONS TO THE LIBRARY.

BOOKS, see p. 105.
OFFICIAL PUBLICATIONS, see p. 108.
PAMPHLETS, see p. 110.
DIRECTORIES, ANNUALS, &c., see p. 114.
CALENDARS and COLLEGE REPORTS, see p. 115.
PHOTOGRAPHS, see p. 116.
PUBLICATIONS OF SOCIETIES, &c., see p. 116.
PERIODICALS, see p. 121.
ADDITION TO MUSEUM, see p. 123.

BOOKS (in order received).

Workshop Receipts, Vol. IV (new ed.); from the publishers.

The Story of the Evolution of the Spinning Machine, by B. P. Dobson; from the author.

The Mechanical Engineers' Pocket-Book (8th ed.), by William Kent.

Milling Machines and Milling Practice, by D. De Vries.

Hydraulics for Engineers and Engineering Students, by F. C. Lea.

Applied Thermodynamics for Engineers, by W. D. Ennis; from the publishers.

Metropolitan Drainage, 1857–8: Report by Capt. D. Galton, J. Simpson and T. E. Blackwell; Ditto, Report by Messrs. Bidder, Hawksley and Bazalgette; Ditto, Correspondence on; Metropolis Water, 1871–2; Manchester Corporation Water Bill, Thirlmere, 1878; Tay Bridge Disaster, 1880; The Penetration of Iron Armour Plates by Steel Shot, by Capt. W. H. Noble; Reports on Breech-loading Rifles; Report on the "Gibraltar" Shields, &c.; Royal Commission on Railways, Reports 1865 and 1866; from Mr. William Pole.

Modern Methods of Water Purification, by John Don and John Chisholm; from the authors.

Reed's Engineer's Hand-Book to the Board of Trade Examinations for Certificates of Competency as First and Second Class Engineers (Text and Plates), (19th ed.); by W. H. Thorn and Son.

Welding, by R. N. Hart.

Hydraulic Turbines, by Viktor Gelpke and A. H. Van Cleve.

The Speed and Power of Ships (Vol. I Text, Vol. II Tables and Plates), by D. W. Taylor.

La Résistance de l'Air et l'Aviation, by G. Eiffel; from the author.

The Anschütz Gyro Compass; from the publishers.

The Newcastle and Gateshead Incorporated Chamber of Commerce Year Book and Commercial Review, by Herbert Shaw; from the Chamber of Commerce.

Electric Crane Construction, by C. W. Hill; from the author.

Traité Pratique de Traction Électrique (2 vols.), by L. Barbillion and G. J. Griffisch; Traité Pratique de la Machine Locomotive (4 vols.), by Maurice Demoulin; Les Locomotives Suisses, by Camille Barbey; Schweizerische Bergbahnen; La Chaudière Locomotive et Son Outillage (2 vols. Text, 1 vol. Plates), by Gustave Richard; from Mr. S. Richardson Blundstone.

Annales Industrielles: Text and Plates, 1869—Pt. 1, 1894; Annales des Ponts et Chaussées: Mémoires, 1869—Pt. 3, 1898 except Pt. 1, 1898; Lois, 1869–71 and 1899–1903; Indexes to Mémoires and Lois 1871–75 and to Mémoires 1881–90; Organ für die Fortschritte des Eisenbahnwesens, 1873–1904; Portfeuille des Machines, 1872–1905 except 1873 and 1876; ditto, 1906–10 unbound; from Mr. W. H. Maw, LL.D. (entered also separately among periodicals).

Internal Combustion Engines at the Brussels Exposition, by P. R. Allen; from the author.

The Evolution of the Parsons Steam Turbine, by Alex. Richardson; from Messrs. C. A. Parsons and Co.

Denkschrift zur Feier der Vollendung der Lokomotive No. 2000: Schweizerische Lokomotiv- und Maschinenfabrike Winterthur, Juni 1909.

A Pathfinder: Discovery, Invention and Industry, How the World came to have Aquadag and Oildag; also, Carborundum, Artificial Graphite and other Valuable Products of the Electric Furnace, a biographical sketch of Dr. E. G. Acheson; from Mr. E. J. Crosier.

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[NOTE.—The following draft Scheme for Associate Membership Examinations was presented with the Annual Report for discussion, and since then it has been revised so as to include an Examination for Graduates and Regulations for their taking while Graduates the Associate Membership Examination.]

APPENDIX.

DRAFT SCHEME FOR ASSOCIATE MEMBERSHIP EXAMINATIONS.

The Council are of opinion that the time has come for instituting an Entrance Examination for the younger applicants for admission to the Institution, to enable them adequately to fulfil the conditions stated in By-law 2.

After the matter had been fully discussed in Committee, the Council made the following suggestions:—

(1) That the Examination should be taken, especially by Graduates, at as early an age as possible, and in order to bring such a scheme gradually into operation, it might be desirable that it should apply in the first year only to Candidates of 28 years of age and under; in the second year to Candidates of 29 years of age and under; and in the third and subsequent years to Candidates of 30 years of age and under.

(2) That no Examinations need be held abroad at present; the effect of which would be that Candidates residing abroad and not having passed an exempting Examination, would have to wait until they reached the age limit at which they could be admitted without Examination. The question as to whether the Examinations should be held in London only or should be held also in the Provinces would have to be considered.

(3) That, as far as possible, Examinations of Universities and Colleges or other public examining bodies should be accepted as exempting from the Institution Examination, it being understood that only such Examinations as were of at least a standard equal to the Institution Examination would be accepted.

(4) That the following Examinations, amongst others, might probably be accepted as exempting Examinations:—

Engineering Degrees of any British or Irish University.

Diplomas in Engineering of the City and Guilds College, University College, and King's College.

Whitworth Scholarships and Exhibitions.

Some other Examinations (for instance, those of Colonial Universities), after inquiry had been made in each case, and the examination papers had been inspected.

Groups of Technological Examinations equivalent to the Institution Examination could, probably, in some cases, be arranged.

The following Scheme of Subjects for Examination (with provisional Syllabuses) has been drawn up by Members of the Council, assisted by specialists in the various subjects:—

Draft Subjects: A, B, and C.

(A)—General Knowledge.

[A short essay on a set subject coming under one of the following heads, one subject being set under each head. One and a half hours allowed.]

(a) Literature,
(b) Science,
(c) Technology,
or (d) Economics, and Workshop Organization.

(B)—Scientific Knowledge.

[Two papers. Three hours allowed for each.]

(a) Applied Mathematics,
and (b) Physics and Chemistry.

[The candidate being required to answer some questions in each subject.]

(C)—TECHNICAL KNOWLEDGE.

[Two papers selected from the following list of alternative subjects. Three hours allowed for each.]

(a) Properties and Strength of Materials,
(b) Steam and the Steam-Engine,
(c) Internal-Combustion Engines,
(d) Hydraulics and Hydraulic Machinery,
(e) Electrotechnics,
(f) Theory of Machines,
(g) Machine Design,
(h) Metallurgy.

DRAFT SYLLABUSES.

(B)—SCIENTIFIC KNOWLEDGE.

(a) *Applied Mathematics.*

Statics.—General conditions of equilibrium; calculation of stresses in frameworks by means of force and link polygons and by the method of sections; shear and bending moment; theorems on couples and wrenches.

Hydrostatics.—Centre of pressure; equilibrium of floating bodies; metacentre; steady rotating fluids; stability of walls under fluid pressure.

Dynamics.—Rectilinear and circular motion; centre of instantaneous rotation; linear and angular momentum; work and energy; centre of mass and moment of inertia; motion about a fixed axis; impulsive forces; equations of motion of a rigid body with simple applications; gyroscope.

(b) *Physics and Chemistry.*

Physics.—Measurement of temperature. Effect of temperature on volumes of solids, liquids and gases. Properties of unsaturated and saturated vapours. Measurement of heat, specific and latent heats. Transmission of heat. Conservation of energy. Properties of mirrors and lenses. Simple telescopes and microscopes. Photometry. Properties of magnets. Magnetic fields. The earth's magnetism. The compass. Properties and measurement of electric currents. Production of electric currents by voltaic and storage cells and by motion of conductors in magnetic fields. Force acting on a conductor carrying current in a magnetic field. Magnetization of iron. The properties of electrostatic charges. Sound and its propagation.

Chemistry.—Elements, compounds, laws of chemical combination.

The gas laws; changes in volume accompanying reactions between gases.

The non-metallic elements, their occurrence, properties and chief compounds. Attention should be paid more particularly to (A elements) hydrogen, oxygen, nitrogen, carbon, chlorine, sulphur, and silicon; (B compounds) water (soft and hard water), ammonia, nitric acid, the oxides of carbon, methane and the paraffins, ethylene, acetylene, hydrochloric acid, the oxides of sulphur, sulphuric acid and silica.

Energy changes involved in chemical combination; combustion.

General properties of the metals. Copper, zinc, aluminium, tin, lead, and iron, their oxides and principal alloys. Behaviour of the metals specified towards oxygen, steam, the commoner acids, and sulphur.

The theory of electrolysis and the chemistry of primary and secondary batteries. The principles governing the applications of electrical methods in the preparation of metals and the commoner inorganic materials.

(C)—TECHNICAL KNOWLEDGE.

(a) *Properties and Strength of Materials.*

Elastic properties of materials. Stress and strain. Hooke's law. Poisson's ratio. Limit of elasticity, yield-point, ultimate strength. Young's modulus. Coefficient of rigidity. Physical constants for cast iron, wrought iron, mild steel, and hard steel. Effects of overstraining and annealing. Fatigue of materials.

Tension, compression, shear, torsion, and bending. Formulas applicable within the elastic limit. Stress ellipse. Combination of bending and torsion. Machines for testing materials. Instruments for measuring strains. Ordinary observations in testing iron and steel. Forms of test-pieces. Elongation and contraction of area. Stress-strain diagrams. Testing of cements and cement mortars.

(b) *Steam and the Steam-Engine.*

Physical properties of steam. Wet saturated and superheated steam. Steam tables. Temperature - entropy and Mollier charts. Fundamental laws of thermodynamics. Reversible and irreversible processes. Carnot's cycle. Absolute temperature. Efficiency of a perfect heat-engine receiving and rejecting heat at constant temperatures. Efficiency of a cycle in which heat is received at different temperatures and rejected at different temperatures. Different modes of expansion. Work done during expansion. Unresisted expansion. Rankine-Clausius cycle for wet, dry and superheated steam. Efficiency. Modifications of the Rankine-Clausius Cycle.

Vapour compression refrigerators. Cycles. Working agents. Coefficient of performance.

Behaviour of steam in engine-cylinders. Condensation and re-evaporation. Wiredrawing. Drop. Missing steam. Indicated steam. Leakage. Lagging. Jacketing. Superheating. Compounding. Influence of size, speed and ratio of expansion. Horse-power and steam consumption.

Testing of engines. Indicators and reducing gears. Indicator diagrams. Compounding diagrams. Steam calorimeters. Brakes and dynamometers. Brake indicated and shaft horse-power.

Steam consumption. Absolute thermal efficiency. Efficiency ratio. Mechanical efficiency. Willans lines.

Valves, valve-gears, and valve diagrams. Governors. Types in use. The dynamics of governors.

Crank-effort diagrams. Fluctuation of speed. Fly-wheels. Inertia of moving parts. The balancing of engines.

Types of steam-engines. Stationary marine and locomotive. Flow of steam through orifices, pipes, and nozzles. Injectors. The steam-turbine. Types. Blade angles and calculations regarding power and steam consumption. Effect of friction between the steam and the walls and blades. Leakage. Fuels. Combustion of fuels. Air supply and regulation. Analysis of flue gases.

Boilers. Types. Heat transmission. Boiler trials and heat balances. Superheaters. Economisers and thermal storage.

Condensers. Types. Heat transmission. Wet and dry air-pumps. Circulating pumps.

(c) *Internal-Combustion Engines.*

Combustion and explosion of inflammable gases and vapours in air. Pressures and temperatures of explosion at different initial pressures. Time of explosion; time of cooling. Effect of combustion chamber dimensions on ignition and cooling. Effect of compression.

Four-stroke engines. Two-stroke engines. Arrangements of inlet and exhaust valves. Igniting devices; flame; hot tube; electrical, low and high tension. Valve arrangements for coal gas, producer gas and blast-furnace gas. Air, water and oil cooled pistons; their design. Water cooled valves. Methods of allowing for expansion of cylinders due to temperature differences. Heavy-oil engines; means for vaporising, ignition by hot enclosing surfaces. Diesel engines; ignition by compression temperatures. Petrol engines; carburettors, electrical ignition, throttle and other control.

Governing; cycles and devices.

Thermodynamics of air cycle assuming constant specific heat. Constant volume and constant pressure engines. Air standard efficiencies. Actual thermal efficiencies. Brake and indicator. Actual maximum and mean pressures in different types of engines.

Indicator diagrams; normal and abnormal. Difficulties of working fluid; pre-ignition and back ignition; late ignition, early ignition. Charging and discharging resistances in four- and two-stroke engines.

Gas-producers of pressure and suction types.

Blast-furnace gas treatment.

(d) *Hydraulics and Hydraulic Machinery.*

Pressure of water at a point. Centre of pressure. Pressure on a surface. Flow of water through orifices, notches, and weirs. Laws of fluid friction. Steady flow in pipes and uniform channels. General phenomena of flow in rivers. Gauging of flow in rivers. Impact of jets on planes. Types of turbines. General principles of design of turbines. Governing of turbines. Types of pumping machinery. Variation of efficiency with lift in reciprocating pumps. General principles of design of centrifugal pumps. General principles of hydraulic transmission of power.

(e) *Electrotechnics.*

Definition of electrical quantities, and Ohm's law.

Electrical and mechanical efficiency, and connection between mechanical, electrical, and thermal units of power and work.

Self-induction and its effect on the output of alternating current machinery.

The generation of heat in electrical machinery by the passage of the current.

General features and principles of action of continuous current and alternating current machinery.

Mechanical features of electrical machinery as applied to different uses.

The use of electrical measuring instruments.

Principles of transformers, rotary converters, and motor generators.

Types of cables commonly employed in factories and workshops.

Comparison between electrical transmission and purely mechanical transmission of power in factories and workshops.

Electric lighting, types of lamps generally employed with current and voltage required by them.

Conductors and non-conductors of electricity and their mechanical properties.

(f) *Theory of Machines.*

Definition of a machine; lower and higher pairing; kinematic chains; quadric and slider crank-chains and crank-chains in general; skew mechanism, such as Hooke's joint; the application of the foregoing mechanisms in the steam-engine and various other types of machinery, such as pumps, hoists and cranes, printing machines, machine-tools, etc.; methods of determining the relative velocity of different parts in a machine, by calculation and by graphic methods; acceleration diagrams of the piston in the ordinary steam-engine; the theory of teeth of wheels, the path of contact; mode of ascertaining correct form of teeth for constant velocity ratio of two wheels; wheels in trains; epicyclic gearing and reverted trains; application of wheel trains in screw-cutting machinery and change-speed gearing for machine-tools and motor vehicles; ratchet mechanism; theory of cams, and mode of describing their outline to produce any required motion; application of cams in machinery; self-feeding for machine tools; return motions; method of effecting different velocity ratio with belts, length of belt and diameter of pulleys; anti-friction devices of various kinds; governors and governing devices, appliances for measuring speed and acceleration; indicators and indicating appliances, revolution counters, speed indicators and speed recorders.

(g) *Machine Design.*

Answers to questions requiring drawing are to be in the form of carefully drawn and dimensioned hand sketches.

Questions will be set on the design of the following:—

Fastenings, including riveted joints, bolts, joint-pins, nuts, keys, cotters, stays; journal and thrust bearings, plain, ball and roller;

crank pins, shafts, axles; couplings, box, flange and friction; connections of all kinds, such as Oldham clutches and universal joints; supports for shafting, pedestal, foot-steps, axle-boxes; gearing, belt gearing, the joints, modes of tightening, proportion and construction of pulleys, plain and stepped; the design of pulleys for rope and wire-rope transmission; chain driving, different designs of chains and the design of sprocket wheels; tooth gearing, design of teeth, cycloidal, involute and other forms; teeth of wheels, their form and strength; bevel wheels; screw gearing; design of worms and worm-wheels; the mode of designing and cutting helical and screw gearing; design of pipes and cylinders; design and strength of cranks and levers, rams, pistons and piston-rods, valves and cocks; design and arrangement of lubricators and lubricating systems.

(h) *Metallurgy.*

The physical properties of metals generally used by engineers: density, varieties of fracture, malleability, ductility, tenacity, conduction of heat and electricity. Action of heat, welding. Effects produced by hammering, rolling and annealing. Elements of metallography. Characters, composition and uses of the chief fuels. The regenerative system. The chief forms of pyrometer and their applications and materials used in the construction of furnaces.

Principles of iron and steel manufacture. The chief processes. Composition, physical properties and uses of iron, steel, cast-iron, high-speed tool-steels and other special steels. Acid and basic steels. Classification of ordinary steel for tools, springs, etc. Effects of carbon, phosphorus, sulphur and other elements on iron and its alloys. Hardening and tempering. The chief ores of copper, lead, tin, silver and gold. Outlines of the methods of extraction of these metals and the principles and chemical changes on which they are based. Physical properties and uses of copper. Composition, physical properties and uses of the chief alloys of copper, tin and lead; brasses, bronzes, bearings and anti-friction alloys, and type metals. Electro-deposition of copper, nickel, and silver. Corrosion of metals.

NOTE BY THE PRESIDENT ON THE PROPOSAL FOR EXAMINATIONS.

It has long been recognized that, under the existing regulations, very great difficulty is experienced in determining with anything approaching precision what is the "good general and scientific education" which Candidates for admission into the Institution are assumed to possess when approved by the Council for ballot. Certificates of proficiency in certain engineering subjects obtained after study at evening classes at some Technical Institute, or from the Board of Education, are at the present time all that can be shown by perhaps the majority of Candidates; and in such cases practically the only test of qualification that can be relied upon is the nature of the apprenticeship served and the subsequent experience.

There is, however, a general consensus of opinion that a Mechanical Engineer's training in the present day should embrace a wider field of study and of knowledge than can be obtained in the workshops alone. It is conceded that this does not in the least diminish the great importance of training in and on works, but young men cannot be properly trained to take control of works in mechanical engineering at the present day who have not effectively studied and mastered those scientific and technical principles which are the very foundation of all engineering progress. The argument that is sometimes heard, that many of the best Engineers now living have not had the kind of training referred to and that their success proves that theoretical studies are of but comparatively slight importance, is invalid, because the conditions governing the question are no longer what they were when such men were learning their business. It is quite evident that the successful control of engineering works is becoming more and more dependent upon scientific methods, and men who are lacking on the scientific side of their profession will find themselves more and more handicapped in the struggles of their careers.

So far, there is not probably any very acute difference of opinion. Controversy arises on the question as to whether an examination is of any great value as a test of real knowledge. It may be admitted that too great an importance is frequently, if not generally, attached to the results of examinations, and that it is, after all, the prolonged and consistent study with a view to the academic training of the candidate which is of the greatest consequence. Nevertheless, the examination is, in fact, the only test that is available.

It is considered that an examination test is imperative in order to secure the minimum of study desirable, but the results of the examination should be subject to a common-sense review by the Examination Committee who would control, not only the appointment of examiners, but even, to some extent, the examination questions set. The Committee could take into account the opportunities for study available for the Candidates, and have before them the general reports of the tutors under whom the candidates were studying. There are pitfalls in any examination system, but it has become essential that examinations should be required from all the younger Candidates in order to secure the desired status of membership of the Institution of Mechanical Engineers. Examinations have been in force in the Institution of Civil Engineers for many years. The Institution of Electrical Engineers have determined to adopt the system, and it is clearly desirable that the Institution of Mechanical Engineers should require for admission an equivalent qualification. From a national point of view, English Engineers should not be satisfied with less than has been recognized as necessary for superintending Engineers in foreign countries.

The examination period in an Engineer's life should not extend beyond the age at which full Membership is possible, but all Candidates under that age (at present fixed at thirty years) should be required to pass this test without in any way lessening the importance of thorough practical training in works and drawing office. The present age-limit for admission to Associate Membership is twenty-five years, and a great practical advantage of the examination to the younger men would be that any Candidate who had passed satisfactorily through both his practical training and the examination, would, if he were engaged in engineering work, be passed for ballot, even though his position did not indicate much independent responsibility. A young man thus admitted as an Associate Member of the Institution would, if the suggestions of the Council are realized, be better fitted to obtain a really responsible position than others who could not show such a qualification. It is quite reasonable that those who have not gone through a similar course of study and training, or have shirked the ordeal of examination, should have to wait until they have obtained a recognized position of responsibility before becoming eligible for admission as Associate Members or Members. Candidates at the age of twenty-five, if fully trained in theory and practice and if doing engineering work, should be eligible for Associate Membership. If they are Graduates it is not asking too much to require them to pass such an examination as has been outlined, or some other equivalent examination, after a recognized course of study in some Engineering College or Technical Institute. There should, however, be an interval of time before the full scheme comes into operation, and it is with this object that it has been suggested that for the first year the age-limit for admission without examination should be twenty-eight years—the maximum age for Graduates to remain in the Institution as such. In the second and third years after the examination system had been started, it is recommended that the age-limit would be twenty-nine and thirty years respectively; and it is suggested that any extension of age-limit in the future should be limited by the age at which full Membership is allowed by the By-laws.

The success of the scheme as a whole must depend on mutual confidence and understanding between the Council and the members generally, and it is essential for the prosperity of the Institution at this critical stage in its history that members should have the opportunity of freely expressing their views upon the proposals made.

Discussion.

The Chairman (Sir Frederick Donaldson) thought the members would agree that the Report was sufficiently comprehensive without his entering into any detail about it. There was, however, one clause to which he wished to direct special attention, namely, that dealing with the question of the qualifications for membership which Mr. Ellington adumbrated in his Presidential Address last year. It would be noticed at the end of the paragraph that the Council were desirous of having the question thoroughly ventilated, in order that they might be assured that the great majority of members approved the proposal. The discussion of the subject might possibly extend over some little time, and it would therefore probably be convenient if he at once proceeded to invite those present to adopt the Annual Report, leaving the discussion of that particular subject to be taken in conjunction with the Appendix and the Note by the President, which was given at the end of the Report, which he proposed reading later. If that was in accordance with the members' views, he would announce that the discussion on the Report was now open, subject to the suggestion that the members be asked to reserve any remarks they had to make on the qualifications question till later in the evening.

Mr. Daniel Adamson asked the members present to extend to him their forbearance if he was not as practised a speaker as they were accustomed to listen to, as it was only the strength of his convictions that brought him to his feet that night to criticize the management of the Institution. He had taken the opportunity that afternoon to visit this present home of the Institution, and as a result he was inclined to say, paraphrasing what had been said many centuries ago: "Happy are thy Council and happy are these thy London members, who can attend continually before thee." He would that he could say also, "Happy are thy country members." The Institution possessed a magnificent building, and all members would agree that it was to the advantage of the Institution to have a monumental headquarters, if only as an outward sign of the importance of Engineering to the rest of the world. But the foundations of such an Institution depended upon the sympathy and interest evolved amongst the general body of members; and he therefore urged the Council, now that the home of the Institution was on the point of completion, to give more consideration than had been the case in recent years to the members from the country who could not attend the meetings regularly, and who could not avail themselves of personal visits to the fine Library that the Institution possessed.

One of the most important subjects to which the Council should give their attention was that of more practical research. Of recent years the members had not had the results of any valuable Researches given to them. At present everything seemed to be stagnant. If the present year's Report and last year's Report were referred to, it would be found that very important subjects which were suggested to the Council after consultation with the members were in abeyance, namely, "Steam-Jackets," "Friction of Gearing," and "Heat Transmission." One or other of those subjects interested every one present, and he therefore pressed with all the energy of which he was capable for the resumption of practical work on all of them. He did not see why all three subjects should not receive prompt attention. He had not embarked upon his mission that evening without consulting a few of his fellow members. He had received very favourable replies to his suggestions from many who were not able to attend, and with the permission of the Meeting he would like to read a short extract from one of them. It was certainly the most outspoken, but he asked those present to remember that the remarks were those of a member criticizing his own Institution, which he had a perfect right to do, at the Annual Meeting, which he was not able to attend personally:—"I have been round to numerous people with your letter and all are agreed that, compared with what might be done, very little notice is taken of those of us who do not live in London. I think it is sixteen years since the Committee to investigate the effects of Steam-Jackets was constituted, and during the whole of that time they have

(Mr. Daniel Adamson.)

scarcely contributed anything at all to our knowledge of the subject. If they had really wanted to find out anything about Jackets they would have seen that Manchester had an experimental engine admirably fitted for work on that subject and asked someone there to join the Committee. But Manchester is not London, and the staff of the School of Technology had the misfortune to be interested in engineering problems rather than in the academic nonsense prevalent in other places." He wished to say that he had the permission of the writer to read the letter, although possibly if the member had known it was to be read at the Meeting, he might have expressed it somewhat differently. He thought those present would however agree that there was room for something in the way of more practical research being carried out by the Institution.

Another thing which he urged the Council to take up as soon as possible was the abstracting of technical literature which was mentioned in the Report. It was unnecessary for him to enlarge upon the necessity of such abstracting for mechanical engineering purely as distinguished from the other branches which were already dealt with by other Societies. The fact that over 700 members had voted in favour of it, in addition to others who had not taken sufficient interest in the subject to reply, some of whom it was to be hoped were in favour of it, was sufficient proof of the importance of the subject to the Institution. With the permission of the Meeting, he desired to allude to one or two objections which he had heard raised to the proposal. The first objection was the question of cost. In the circular which the members received a few months ago, the cost was suggested as amounting to from £2,400 to £4,000 per annum. Some of the members might know that the Institution of Electrical Engineers issued a very valuable publication known as *Science Abstracts*. That publication cost the individual member, who cared to subscribe to it, 7*s*. 6*d*. per annum, including binding, and it cost the Institution of Electrical Engineers between £300 and £400 per annum—not thousands as suggested in their own Institution's circular. The Iron and Steel Institute issued, as part of their Journal, a most important series of abstracts of articles appearing in the technical Press of the world bearing upon the iron and steel industries. That cost the Iron and Steel Institute between £400 and £500 per annum, and it did not cost the members who received it anything more than their annual subscription, which most of those present knew was about two-thirds of the annual subscription paid by the members of the Institution of Mechanical Engineers. Another objection raised was that the ground was already covered. Some of his friends told him that publications were already issued which covered the ground, but his objection to that was that they did not cover the ground from the point of view of Mechanical Engineering: they covered too much ground, with the result that, if a member of the Institution wished to be posted up in foundry work, he must subscribe to the Iron and Steel Institute; if he wished to be posted up in Power Engineering he must subscribe to the *Science Abstracts* issued by the Institution of Electrical Engineers; and if he wanted to cover the rest of the ground, one of his friends said he must subscribe to the *Engineering Magazine*. It might be that the members would have to subscribe a guinea for the Abstracts, and it would really be a saving to them if they could get it for a guinea, but he would subscribe the guinea under protest because, judging by the expense to other Institutions, it was not a necessary item. Another objection which had been raised was that newspaper proprietors and their advertisers would not approve. His own experience, however, was that the particular newspaper proprietor was wrong, because he personally had made the acquaintance of more technical papers by reading Abstracts than ever he would have done if he had confined his reading to the originals. During the Birmingham Meeting, eighteen months ago, he spoke to the Secretary of the American Society of Mechanical Engineers in connection with this subject of abstracting, and Mr. Calvin Rice at once said that his Society would co-operate with the English Society. Things moved much more quickly in America than in this country, and he was pleased (or otherwise) to see that during the present year the American Society had begun publishing Abstracts, by publishing in their monthly Journal what they called a foreign review. They dealt with the European papers first as being no doubt of greater importance to their members. Some of

(Mr. Daniel Adamson.)

the members had been in hopes of obtaining a Monthly Journal from the Council for over three years. The American Society published a Journal month by month, and his own experience was that it was a real tangible reminder of the activities of the Institution to those distant members who were unable to attend the Meetings, and the advertisements paid for it. Another advantage of the Journal was that, coming out in monthly parts, a large amount of material which was not of sufficient value to be bound in the permanent Records was issued in that form. The members saw it and it answered its purpose; whereas if there was no such vehicle, the Institution was bound to print much unnecessary matter in the annual volume.

There were one or two points of smaller importance to which he wished to refer in conclusion. In the first place, other Institutions had benefited largely by the development of Local Sections. Whether the establishment of Local Sections would be an advantage to the Institution of Mechanical Engineers was a matter for the Council to consider. Another point of detail was whether holding the meetings on Friday night was the most convenient time from the point of view of the country members. He merely asked the Council to bear that point in mind if the matter came up for discussion. He had been told recently that the increase in Membership was a sufficient answer beforehand to any criticisms he could make; but, to quote an anonymous writer of about five years ago, the Institution was "putting on fat rather than muscle." In proof of that assertion, he asked the members to turn to the present Annual Report, in which it would be seen that, during the past year, only two Papers had been read by ordinary Members out of a total number of members of 2,500. He suggested that the Institution did want a little stirring up. If the gentlemen of the Council would allow him to say it, he thought that more frequent changes in the Membership of the Council would be an advantage. He desired to be allowed to say that in the remarks he had made he did not wish to cast any reflection on any individual Member of Council. Those of the Council who honoured him with their acquaintance, however slight, knew that he held each of them in the highest esteem, but he believed that a new Member of Council did attract a certain amount of new support. This aroused new interests, it enabled new subjects to be suggested, and the new Member of Council was generally of sufficient eminence to know some supporters who would give the Institution a Paper on a certain topical subject if required. He was sorry that their esteemed President was not present to hear the next criticism, or suggestion, he desired to make, but he wished to express the opinion that it would be in the interests of the Institution if the President held office for one year only. The advantage of what he suggested was that if a good man was chosen as President, he was able to devote more of his energy to the advancement of their interests during his one year of office than if he spread it over two years; and if a poor man were obtained, which God forbid, the members were rid of him more quickly, before he had done very much harm. In fact, in thinking over the matter it seemed to him that what he was urging in regard to the Council was analogous to his friend's (Dr. Nicholson) theory of high-speed heat transmission—that the faster the molecules, or the members, were moved through the Council room the more would be got out of them in a given time. He thanked the members for listening to him so attentively, and he only wished he had been able to do more justice to what he believed was a good cause.

Mr. **Edward C. R. Marks** said he desired to give general support to Mr. Daniel Adamson, who had come from Manchester to the Annual Meeting to state the case of the country members. He himself was also a country member, coming from Birmingham, and he wished to point out that if the people of his city were boastful, it might remind them that Birmingham was the home of the Institution. The Institution's youngest years were spent there; but the Institution moved to London, and some time after he moved from London to Birmingham. Mr. Adamson's remarks had covered a very wide field, and personally he wished to give general support to his case without of necessity committing himself to all its details. There was, however, one point to which he wished to refer for a few moments, namely, that he believed in

(Mr. Edward C. R. Marks.)

the establishment of Local Sections. There were in Birmingham, Manchester, and other cities Local Sections of the Institutions of Civil Engineers and Electrical Engineers, and he saw no reason why their Institution should not do a similar service for its members who lived in the country, and who comprised the majority of the members of the Institution. At the local Dinner of the Institution of Civil Engineers usually the President, the Secretary, and one or two other Members of Council were present. They gave the visitors a Dinner, and subsequently their views on matters which the Local Section thought should be put right. He wished for the benefit of the Institution, as well as that of the country members, that Birmingham could have the advantage of seeing the Council of the Institution present at a meeting held in that city. Neither Mr. Adamson nor any other member had any other purpose in view than to do what he could to improve the Institution to which he belonged. The Institution of Mechanical Engineers was a body of which they were proud to be members, but they wished to see it taking its rightful place in the engineering world. It would be a great advantage to those in the country if they could meet together from time to time—not necessarily to hold a meeting once a month, because he knew there were local bodies which in a measure filled up the gap; but they should meet two or three times a year. And above all, they should have a Dinner in the country. He believed a great deal in such Annual Dinners. It brought the members in contact with each other, and they would then meet the gentlemen composing the Council. He urged the Council to take the matter into their careful consideration, and to establish Local Sections as soon as possible.

Mr. Andrew Brown said, regarding the request that had been made for a synopsis of the Proceedings of foreign engineering, that as only about one-eighth of the members desired to have a synopsis, he really did not think it was the wish of the Institution that it should go to such an expense. Personally he thought that the one-eighth who desired the Abstracts should be left to look after themselves as best they could.

With regard to the question of the benefits that might be derived from the Institution, he was inclined to suggest that a number of really good free lectures, after the style of the Gresham Lectures, open to the public, dealing with engineering subjects might be given, and thus show to the world in general that the Institution was prepared to do something for the young and rising generation.

With regard to the question of the Benevolent Fund, it was said in the Report that certain rules and regulations had been placed before the Board of Trade. He desired to ask the Council at this early stage to take into consideration what he thought was an important point, namely, that they were inclined to go too much by the rules of other societies. The particular rules that he was most acquainted with were those connected with the Institution of Civil Engineers' Benevolent Fund. There was one thing he thought respecting member applicants that ought, if possible, to be avoided. About two or three years ago he made it his business to make some enquiries on the question, when some money was granted to this Institution to be used for benevolent purposes, but as no machinery existed at the time the money was handed to some other purpose and the matter dropped. A gift of a thousand shares in Messrs. W. H. Allen, Son and Co. had now been made to the Benevolent Fund, which would prove a very great boon, and if the Benevolent Fund was to be proceeded with, he would like consideration to be given to the following suggestion. He thought that instead of making the applicant almost a pauper by the process of application, a Committee should be formed which should take into consideration any cases of distress which came to its notice. When he used the words "cases of distress" he did not simply mean cases of widows and orphan children, but cases of members of the Institution who might (under circumstances that could be explained privately) have fallen on bad times owing to an accident or a necessary operation, or be laid up and unable to do their work in the ordinary course. He thought the Committee should be able to go to those people privately, on the suggestion perhaps of a member, and make a small donation—it might be

(Mr. Andrew Brown.)

£10 or £20 or anything; but not necessarily to make that particular person feel that because he was in difficult circumstances for the time being he would become a pauper by making a written application giving a list of his friends, and saying who were his nearest relatives in the engineering world.

The Chairman, dealing with the various points raised by members, said Mr. Adamson had referred to the want of result of the Researches. As a matter of fact, in the Report two Papers were mentioned as being in course of preparation dealing with two of the Researches. It was true that the Steam-Jacket was not one of them, and whether that was ever going to be free from the "academic nonsense" to which Mr. Adamson referred, he could not say. The Council hoped that they would be able to earn better opinions from Mr. Adamson in the future in that connection.

Mr. Adamson's suggestion with regard to the Abstracts and the suggestion made by Mr. Brown were so distinctly opposite that the Council must be in a position of great doubt as to which was right, if it were not for the fact that the numbers of those gentlemen who had thought it worth while to reply to the circular letter, enquiring what the members were prepared to do and what their wants were, seemed to show that the interest was by no means universal. Personally he could not but regret that that state of mind should exist among the members. He would very much like to see Abstracts published in really useful form. Whether an index only would meet the requirements he was not prepared to say. The present view of the Council, however, arising out of what they had gathered from the various replies and letters they had received, was that the amount of support, so far indicated by the members, was quite inadequate to warrant the Institution undertaking the proposed preparation and publication of Mechanical Engineering Abstracts. That was a conclusion which he thought they could not fail to come to when only about one-fifth of the members answered the questions, of whom only 13 per cent. of the total membership were in favour of the project, and 12 per cent. willing to support it financially. That something might ultimately come out of the suggestion he thought was quite possible, because there were, as Mr. Brown suggested, other means by which the data could be obtained, and he thought it was quite possible that some of those other means might be made available to members at prices less than to the general public. It was too early to say anything on that point yet. The only point the Council were clear about was that the funds of the Institution could not, in view of the response which had been received, be used for that particular purpose. The Council would, he was quite sure, consider Mr. Adamson's suggestion as to the day of the meeting, but he believed it had been considered in the past, and though it was generally regarded as a very unlucky day, he did not know that it had been so for the Institution. The "general shuffle-up of the Council" was a matter which would no doubt receive very careful attention.

With regard to the question of a one-year Presidency, he did not know that, as he was only in temporary occupation of the Chair for the moment, he would be justified in going so far as to say that he agreed with the suggestion. As a matter of fact he did agree that it might be possible to think the Institution had now reached such a size that (unless some very particular piece of business was incomplete) the Institution might be better off if the Presidency was only held for a year.

Mr. Marks had suggested that what he supposed would be called Sectional Meetings should be held. All he could say in reply was that that particular question had recently been under discussion, but it was not very clear how any useful end could be attained at present. At the same time he could promise Mr. Marks that the Council would not fail to take proper cognizance of the suggestion.

One other question had been raised with regard to the Benevolent Fund. The Council were advised that to make it properly effective the Fund would have to be managed by an organization in the form of a private Company under the Companies Act, but the working of it would no doubt be done with all due and sympathetic regard to secrecy. If it were done with all secrecy, and the recipients of any funds which could be distributed were known only to the

(Sir H. Frederick Donaldson, K.C.B.)

members of the Committee who worked it, he failed to see that there need be any fear that anyone would be made to feel anything more than the usual sadness which "hard-upness" brought. He was quite sure that not only the Members of the Council, but the Members of the Committee of Management of the Fund would set as their ideal that, if there were funds to distribute for the benefit of those who were temporarily or permanently ill off, distribution should be done with all due regard to thoughtfulness and kindness.

The Chairman said that, if there were no further speakers, he would formally move the adoption of the Annual Report.

Dr. W. H. Maw seconded the motion, which was adopted without dissentient.

The following Resolution was subsequently carried, with one dissentient:—

> "That this Meeting generally approves the proposal that each Candidate (of an age at present fixed at thirty years and under) for class up to Associate Membership should (in addition to requirements embodied in the present By-laws) afford satisfactory evidence of training, either by suitable educational tests or by passing an examination initiated by the Council on behalf of the Institution; and that the Council be requested to draw up any alterations in the By-laws which may be necessary, for submission to the members at a future Meeting."

The Meeting terminated at a Quarter past Ten o'clock. The attendance was 156 Members and 26 Visitors.

Communications.

Mr. C. E. **Baldwin**, while writing approval of the Council's proposal re examinations, wished again to draw attention to the advantage of holding more frequent provincial Meetings, and thought that such a course would further the cause of the Institution. He added that so few of the younger members of the Institution had an opportunity of going to London to the Meetings of the Institution, where in a district like Tyneside an occasional Meeting, if only twice a year, might afford opportunities of discussion which were denied at the present time.

Mr. **David E. Roberts** (Cardiff) wrote that the Inaugural Meeting of a Local Section of the Institution of Electrical Engineers had been held in Cardiff. There was also in that district a Students' Section of the Institution of Civil Engineers, and he felt certain that the members of the Institution of Mechanical Engineers in South Wales outnumbered the members of either of the two bodies mentioned. He thought there would be an advantage if a Local Section of the Institution of Mechanical Engineers were established, and he would be very pleased to assist in the formation of such a Section.

The South Wales Institute of Engineers possessed a fine building in Cardiff, and had very kindly granted facilities to both of the above Local Sections, and he had no doubt that they would be equally disposed to welcome on similar lines a Local Section of the Institution of Mechanical Engineers. He added that the Sections referred to covered the districts on both the Cardiff and the Bristol sides of the Channel.

EXAMINATIONS.

The CHAIRMAN (Sir Frederick Donaldson) said that the members, at his request, postponed the consideration of the Appendix to the Report dealing with the question of Examinations, which he now proposed to discuss. It would be seen on page 89 of the Report that the Council desired to have the question thoroughly ventilated and to be sure that the great majority of the members approved the proposals. The scheme had been the subject of very careful and lengthy consideration. The Committee, which had considered it, had not confined itself to its own brains, but it had drawn upon the brains of many other people outside, whom it considered were well qualified to give assistance in a matter of that kind. He did not know whether all the members had read the draft scheme. He had reason to think that some of them had read it perhaps rather perfunctorily, and some of them without a full appreciation of what the scheme propounded. It had been brought to his notice that evening that one member at any rate had overlooked the fact entirely that the incidence of the Examinations proposed was intended to go up to the age of thirty only; so that the member who regarded it as ridiculous that a man of forty should be invited to submit himself to an examination was, he thought, exercising himself unnecessarily, because that was not the intention. Then, again, the draft syllabus was divided into heads. In print it looked rather a formidable undertaking, but if the Draft were investigated rather more closely, it would be found that really the number of papers that were required were only two each besides the first one, which was merely a thesis at present. The President had taken the keenest interest in the matter, and had submitted a Note at the end of the Report which he now proposed to read.

(The CHAIRMAN read the "Note by the President on the Proposal for Examinations" appearing on pages 131–3.)

He considered that the President's Note was a most valuable basis on which to found the discussion for the purpose of obtaining, as he hoped they would do that evening, the clear and distinct approval of the members of the general lines which had actuated the Committee and the Council in bringing the proposal up to its present stage. The discussion on the Examinations question was now open, and the Council would be pleased to hear any comments which any member had to offer.

Mr. E. G. **Constantine** desired to say at the outset how disappointed he was that the President was not present. All the members felt that the disappointment on Mr. Ellington's part would be exceedingly keen, as he had taken such immense interest in the question of qualifications for members of the Institution. All were agreed on the necessity of raising the status of the Institution to the highest possible point. They were all agreed also that the syllabus which had been put forward by the Council was a right and proper one if an examination was to be passed. Whether it would have that effect, or whether it would have the effect of excluding otherwise eligible members, could only be determined by time. His own fear was that unless the examination system, if it was installed, was very carefully worked it might have quite a contrary effect from the one desired, and that the effect might be that instead of raising the qualifications of the members as engineers, it might mean the influx of a very considerable number of men who might have high academic attainments, but who as engineers, as they understood the term, were lacking.

To make his meaning clear, he wished to refer to two concrete cases of men he had known. He knew a man who was highly educated—as a matter of fact he was destined in the first instance for the Church. By some inscrutable means he was switched off from the Church into Engineering. He went through a course of theoretical and scientific training; he went through a course of workshop practice; he went to sea; he passed his examinations as a marine engineer—in fact examinations were never any trouble to him. But every position of responsibility which he obtained he could not retain. He was a man who was a slave to duty, and so painfully anxious to do the right thing that he never succeeded.

(Mr. E. G. Constantine.)

The last he heard of him was that he was working as a shore-gang fitter at Birkenhead. That man would have passed the examinations that the Institution proposed to adopt without any difficulty; he would have been eligible as far as general and scientific training were concerned to be a Member of the Institution, and the difficulty would have been to have kept him out. But he was not an engineer.

Another case was that of a man who was a Member of the Institution, and who he had no hesitation in saying was one of the finest engineers of the day, who at thirty years of age, unless he was very much mistaken, would have found it impossible without very hard cramming indeed to have passed the examination that was proposed. That man was an engineer in every sense of the word—a man who could design and construct anything from a marine engine or a steamship to a cotton mill or a dry-dock. That man, unless the Council or the Committee of Examinations exercised the power given to them—and that was the saving clause to his mind in connection with the proposed innovation—and saw the "engineer" in the man, would not have been elected until after thirty years of age. Those were two concrete examples of the extreme cases perhaps, but they had to be reckoned with, and the question was how were the Council to reckon with such cases? He begged the Council to be very, very careful indeed, before introducing the innovation, to make quite sure that it would have the intended purpose of raising the qualifications as engineers of members of the Institution.

Mr. B. A. **Raworth** said he was sure the members must all feel most sympathetic towards any attempt the Council might make to raise the status of engineers. It was the fact that the status of engineers was not what it ought to be, considering the important part they played in the world and how modern civilization rested upon their efforts. If an examination would do that—if it would raise the status of engineers—by all means let the Institution have examinations. Let the young men face the music, and prepare themselves for the ordeal. But they did not want to sail under false colours. If the new members that were admitted by examinations were going to be worse engineers, and not as efficient engineers as those who had been admitted by selection, then there would be no advantage either to the profession or to the Institution. According to the new scheme there were two methods of entering the Institution. The President had said in his Note just read that Associate Members might enter in two ways, first between the ages of twenty-five and thirty. They might enter by serving an apprenticeship, or what was the modern equivalent of an apprenticeship, and by passing an examination. After the age of thirty they would only have to submit to a scrutiny on the part of the Council. According to the paper before the members, the Council would have no power to scrutinize the career of a young man who had passed his examination and had been through his apprenticeship.

The Chairman said that was not the case. Mr. Raworth had taken no notice of the By-laws.

Mr. Raworth said he was following the Note by the President.

The Chairman said the point was provided for in the By-laws.

Mr. Raworth, continuing, said the Note stated that:—"A great practical advantage of the examination to the younger men would be that any Candidate who had passed satisfactorily through both his practical training and the examination would, if he were engaged in engineering work, be passed for ballot, even though his position did not indicate much independent responsibility." Surely that was a case in which the Council could not scrutinize the work that a Candidate had done, provided he had passed an examination. If, however, that Note was to be read in conjunction with the By-laws, and the proposed members still had to produce evidence that they were holding independent positions, then, of course, there was very little to be said against examinations from that point of view. The examinations that were going to be held were, he

(Mr. B. A. Raworth.)

understood, to be of a very liberal kind. The Council was to select the examiners; it was to edit the questions if necessary, and so on. But it was very difficult to get an examination for which a student could not be crammed. The Admiralty had tried to frame such an examination, and, when it adopted its new scheme of entry for boys, said, "We will have no more examinations." The boys were interviewed by Admirals and Captains; they were asked all manner of questions about things in daily life; they were told to shut their eyes and say what they had seen in the room, and so on. For a time that was very effectual, but now all masters of preparatory schools prepared boys to meet such questions. They knew every question that could be asked, for there was a limit to the number of tricks that could be played upon boys of twelve years of age. The consequence was that the boys were crammed for the examinations just as they were for all others. He trusted the examinations that were going to be carried on by the Institution, if the scheme was adopted, would at any rate not be susceptible to that kind of treatment.

The Chairman said it might help to an understanding of the question if he read to the members the kind of Resolution which he hoped they would arrive at, and which he thought covered the points that had just been raised:—"That ...... each candidate (of an age at present fixed at thirty years and under) for class up to Associate Membership should (in addition to requirements embodied in the present By-laws) afford satisfactory evidence of training, either by suitable educational tests or by passing an examination initiated by the Council on behalf of the Institution;......" He need not read the rest of the Resolution, which he would put later on. He thought that point covered the ground which Mr. Raworth had mentioned.

Mr. Raworth said it did so precisely.

Mr. Andrew Brown heartily agreed with the Council's suggestion of carrying out an examination. He desired to make a few remarks, particularly on behalf of those young men who were apprenticed at the ages of fourteen or fifteen, and who would never have throughout the whole of their career any opportunity of going either to a Technical College or to a University for the purpose of passing an academical examination. There were thousands of young men who went into their apprenticeships at fourteen, fifteen or sixteen years of age, who spent the whole of the evenings in the first six or eight years of their business lives working up for science examinations, and who succeeded in passing the South Kensington Science and Art or the Board of Education Standards of Examination. What he would like to suggest in considering the question of examinations was that young men who had been diligent students at home, who had attended classes and succeeded in passing the various elementary, advanced, or honours examinations in certain subjects, would be taken into serious consideration by the Examiners as having practically passed the Standard Examinations, thereby being entitled to be elected as members of the Institution, without requiring them to go through a second process of examination, when perhaps they were not able to work up all those subjects again for the purpose of sitting for examination. For the benefit of the younger men, he would like to say that in 1887 he was sent out to Bombay to take charge of an engineering works. After a year the business came to grief, and he was suddenly thrown out of employment. Within a week he was selected by one of the large millowners in Bombay to become the engineer and act as general manager of the whole place at a salary of about £45 a month. After he was engaged he was asked for his certificate, but in those days there was no such thing as a certificate for mechanical engineers. The Bombay Boiler Act was then in force, which prohibited any engineer from having charge of an engine or a boiler over 25 h.p. or 50 h.p. unless he was possessed of a certificate. As a consequence nearly all such jobs were given to old marine engineers who had retired from the ships and come ashore. As he had already said, at that time there was no examination, and he lost the appointment, because in this country there was no examination in mechanical engineering. But the Government of India had put in a saving clause, which eventually came to his

(Mr. Andrew Brown.)

assistance, namely, that a candidate for a first-class certificate under the Bombay Boiler Act, on submitting proof of having passed first-class examinations in engineering at home, was entitled to a first-class certificate. It so happened that in his younger days he had passed a great number of those examinations, and when he made the Government of India acquainted with that fact he was presented without examination with a first-class certificate entitling him to take charge of engines and boilers up to and over 500 h.p. He mentioned this in order that the members of the Institution might not be frightened of the examinations. He wished the Council to feel that, and he was quite sure the young men would very readily agree with him also. It was more likely that those men who were a little older and desirous of joining the Institution would be afraid of coming forward before they were thirty in case they were not able to pass the examination.

Mr. C. F. Hunter said that, under the heading of (A) *General Knowledge* (page 125), the proposal was made: " A short essay on a set subject coming under one of the following heads, one subject being set under each head." If the Institution was to have examinations (and he was quite prepared to acknowledge that a great deal might be said against them as well as for them) he suggested that the syllabus in *General Knowledge* might be considerably extended. The ability to write a readable essay would of itself by no means stamp a man as being possessed of good general knowledge. He understood that other examinations in *General Knowledge*, for example, the Matriculation Examination of the University of London, might be taken as exempting from (A) altogether. He thought it might be advisable to combine Section (B) *Scientific Knowledge* with Section (C) *Technical Knowledge* (page 126), so that instead of having three separate headings, (A), (B), and (C), there should be two headings, (A) and (B). Applied mathematics might, of course, be an obligatory subject. Under heading (C) *Technical Knowledge* two Papers had to be selected from a list of alternative subjects. He suggested there that (*b*) and (*c*) might be combined under one heading of say Heat Engines. It would with the present arrangement be possible for a candidate with a knowledge only of Steam and Internal-Combustion Engines to offer (*b*) and (*c*) as two separate subjects, but he thought by no stretch of the imagination could a candidate who offered those subjects only, and who was unable to answer questions in the other branches, be considered for a moment to be an engineer. He strongly suggested that instead of asking for two subjects in Section (C) it should be made compulsory that a candidate should offer three. There were Properties and Strength of Materials; Theory of Machines; and Machine Design—vastly important subjects which might be left alone by a candidate who offered simply Steam and the Steam-Engine, and Internal-Combustion Engines.

Mr. J. K. Aykroyd (Chairman of the Committee of the Graduates' Association) said he had accepted the invitation of the President given at the Graduates' Dinner on the previous Friday, namely, that the Graduates should speak for themselves in regard to the suggested scheme of examinations. It was quite an unusual position for him to occupy to be addressing a Meeting of the Institution, and he felt highly honoured both at being asked to speak before the members and also as Chairman of the Graduates' Committee. There were several points that the Graduates wished to bring forward, the first being the shortness of notice that the question of examinations was to be discussed at the Annual General Meeting. It had made it impossible to call a General Meeting of the Graduates; therefore he had been unable to obtain the opinion of them as a whole, and was simply able to express the voice of those Graduates that he happened to know personally. For that reason he hoped the consideration of the subject would be adjourned.

He would like to suggest that present Graduates now over the age of twenty-five should be exempt from the examinations. Then he thought Graduates should be allowed to take the examination as early as they liked, and in sections, but outside candidates who applied for Associate Membership direct to take it as a whole,

(Mr. J. K. Aykroyd.)

thus offering an inducement to men to enter as Graduates. Sections (A) and (B) might be taken at one time and (C) at a later date, as those who were serving apprenticeships and attending Evening Classes should be able to work up for (A) and (B); but he very much questioned whether they could work up for the three together. Personally, he felt that twenty-five was rather an early age for Graduates to go up for Associate Membership. He always understood that an Associate Member of the Institution was a man who had had some responsibility and a good deal of training. The Council increased the age limit for Graduates not very long ago to twenty-eight. He presumed the Council did so because they needed a man to have better qualifications, and on that account he thought that twenty-five was too early an age. There was also the point to be borne in mind that a Graduate did not benefit very much until he reached the age of twenty-three to twenty-five. Those who were in London did not often get a chance to go on the Committee until that age. It was a great advantage to be on the Committee, as much could be learnt besides Engineering, such as committee work, speaking in public, etc.—this he thought was the view taken by the Council.

With regard to the question of the subjects, he thought the Council might possibly extend them with great advantage, because there were many men nowadays who specialized, and who had not perhaps the opportunity of passing a general examination. For instance, the subject of Aero-dynamics was not in the list, and that was a subject which was increasingly becoming quite a specialized branch. In considering the question of men who had specialized, it was necessary to bear in mind those men who had served their apprenticeship, and might have attended a few Evening Classes, and who had been put into quite a responsible position, such, for instance, as an erecting engineer. What chance had such men of passing the examinations when they were on one job for one month, on another job for another month, and were frequently sent abroad? There was no chance for them becoming Associate Members of the Institution unless they waited till the age limit—thirty. No doubt the Council would demand very good qualifications to accept such men without undergoing the examinations.

Mr. JOHN W. WAINWRIGHT said he entirely agreed with the principle of examination as a test for knowledge, but it was the application of the principle that counted. If the questions were straightforward and a real test of knowledge and not the "catch" questions which were so prevalent nowadays, then they were useful, provided the Examination papers were set by men of experience, and the answers showed common sense, and that the knowledge acquired in the course of study could be properly utilized by the candidate. Further, the answers should show that the candidate had the "engineering instinct," and that he could apply the knowledge to design, to manufacture, to keeping in view the question of output where it was possible to go into such questions, and the suitable use of materials, not neglecting the cost of production. It had been suggested that quantities, costs, and estimating might later on take a place in the curriculum. Finally, if the examination was not very carefully watched, it would become, as too many other examinations had become, too academic. There was a certain class of professor who he sincerely hoped would not set the papers. There was another class of professor, however, for whom the members had the greatest respect. If those professors and others who were so obviously suitable set the papers, the latter would be all right and the results would probably be such that they would encourage a wider range of study with resulting benefits to the candidates and to the Institution.

Mr. GEORGE P. SPOONER suggested that it would be advisable, in considering the question of the Institution Examination, to bear in mind what was done by other nations. He himself was educated forty years ago in Germany, and he was therefore well acquainted with the system adopted in that country for the education of engineers. It took five years for an engineer to pass through the College course, and the examination lasted six months. The student under prescribed conditions could work out some of his examination at home if he liked, or if at College he could take his notebooks with him and use them. The student was not expected to be gifted with an abnormal memory, nor to be examined under other conditions than those he would experience when he was in actual service. As a result of its education, Germany had in the last two decades advanced enormously in mechanical manufactures. For entrance to the College a thorough knowledge of algebra, geometry, trigonometry, and the introduction to differential calculus were required. The first year's course of study included differential calculus and analytical geometry, while in the second year the student studied differential calculus, integral calculus, experimental physics, analytic geometry of the three dimensions, and various other geometrical problems, many being applied. He thought the Institution should have a theoretical examination and that the examination should begin with the Graduates as they came in, so that everyone in future who entered the Institution should pass the examination. Then before a Graduate could become an Associate Member he should also pass in a further theoretical examination. If the examination commenced from the time that the young fellow entered, a great many of the difficulties connected with the ages at which the examinations should be passed would be overcome, so that in a few years there would be a great many Associate Members who had joined the Institution by examination. What the Institution required was a good technical experience backed up by theoretical knowledge. The Germans were a great many years ahead of this country theoretically, and as a result they had gone ahead very quickly in the last twenty years. If British engineers had the German engineers' theoretical knowledge and used it, with their intuition as Britishers, he thought they would pretty well sweep the world, and for that reason he thought the Council had done wisely in putting forward their examination scheme.

Mr. Sydney A. Smith (Honorary Secretary of the Graduates' Association) pointed out that although the Council fully represented the Members and Associate Members they did not represent the Graduates, and he therefore trusted that not only would the

Graduates be given a good hearing, but that their defects would be overlooked. Speaking as a Graduate, he wished to be allowed to make a few points, perhaps somewhat bluntly, but certainly not rudely. With that purpose in view he had compiled the following questions and answers:—

Do the Graduates want the examination for Associate Membership?—Yes. Do we agree with the age and conditions for taking examinations?—No. Do we agree with the age for admission to Associate Membership?—No. Do we agree with the list of Colleges whose diplomas exempt as being a complete one?—No. Do we agree with the examinations as drafted?—Not altogether. Do we agree with the admission to Associate Membership without examinations as provided, namely, after thirty years of age?—Yes. Do we agree with the examinations for Graduateship mentioned by the last speaker?—Most of us, No.

With the object of enlarging on some of the points, he desired to ask what was the object of the examination. He presumed it was to raise somewhat the tone of the Institution. Then the point immediately arose: who was going to do it? It was going to be done by men between the ages of twenty-five and thirty, and therefore it must be very carefully considered from that point of view, and the Council would, he thought, find it difficult to look at it from such a standpoint. As he had previously remarked, the Council did not really fully represent the Graduates, because the Graduates had not a member on the Council to deal with the subject from their point of view. With regard to the question of the age limit, every opportunity should, he thought, be given to a Graduate to comply with the new regulations for Associate Membership. Under that heading came the question of ages and conditions of sitting for the examination. He suggested that a Graduate should be allowed to sit for the examination as soon as he became a Graduate. He did not think that was definitely stated in the suggested scheme.

The CHAIRMAN pointed out that the Appendix stated "That the examination should be taken, especially by Graduates, at as early an age as possible."

Mr. Smith said he thought it did not state any age earlier than twenty-five.

The Chairman replied that that was not so; it was up to twenty-eight years of age.

Mr. Smith, continuing, said the Appendix did not state definitely that a Graduate could take it before he was twenty-five, although the Graduates hoped it was implied. He understood now that it was implied, and that Graduates might take the examination as soon as they became Graduates. The Graduates also hoped that they would not be compelled to take the examination all at once, but that they would be allowed to take it in stages.

With regard to the question of the age at which Graduates should be admitted as Associate Members, they differed from the Council's suggestion on that point. The Graduates did not think it would be a good thing for them to become Associate Members at twenty-five years of age. They suggested that no one should be allowed to become an Associate Member until he was twenty-seven years of age. The Graduates would also like it to be laid down that it was legal to be a Graduate up to the age of thirty. In considering the question of whether it would be a good thing for a Graduate to become an Associate Member at the age of twenty-five, the President in his Note had suggested that it would (page 133). He asked the members, however, to consider this point of the chances of a man getting a post. If the Graduate had been allowed, as the Graduates suggested, to take the examination, he could still mention the fact that he had passed the examination for Associate Membership when applying for any particular position. If the age of twenty-five was not altered, how would it affect the Graduates' Association? Speaking as a Member of the Committee, it was found that the average Graduate—he did not refer to the brilliant men—did not take a part in the proceedings of the Meetings until he was about twenty-four years of age, and from that time onwards until he left he helped not only himself but the other Graduates. Through making a start at the Association

Meetings he was able to learn to speak, and in that way was able subsequently to speak at the Institution Meetings. For instance, it would have been impossible for him (Mr. Smith) to speak at the Meeting, even in such poor language, if he had not begun at the Graduates' Meetings. As the Graduates were all of opinion that they did not do that until they reached the age of somewhere about twenty-five, he submitted that the age should be raised. If the age was not raised, he was afraid it would practically mean the shutting down of the Graduates' Association, because unless the advantages were given to the Graduates that they had asked for, why should a man become a Graduate? Why should he not simply wait until he was twenty-five, and then take the examination?

Another argument for taking the examination as early as possible was that the Graduates were at College between the ages of, say, sixteen and twenty-four and wanted to take the examination while they were actually undergoing training at the College. They did not want to have to read up for it again; in fact it would be very hard, if not almost impossible, to take the examination after the men had gone out into the works and had reached the age of twenty-five, and perhaps had to do night work. That brought him to the question of the existing Graduates who were twenty-five years of age and over. Endorsing the remarks of the Chairman of the Graduates' Association, he thought the Institution ought not to ask a present Graduate who was over twenty-five years of age to take the examination, as it would be very hard work for him. The Graduates' Committee suggested that, so far as existing Graduates were concerned, no man over twenty-five years of age should be asked to take the examination, and that a man over twenty and under twenty-five should only take Section C (page 126). He had already stated that the Graduates did not consider that the list of Colleges whose examinations exempted was a complete list, although he was aware that the statement was made that "Groups of technological examinations equivalent to the Institution Examination could, probably, in some cases, be arranged." That was very nicely put, and would undoubtedly pass many Colleges that he had in mind, but was it fair to the Colleges themselves? The statement

(Mr. Sydney A. Smith.)

had been made that the Council desired to raise the tone of the Institution, and that the way to do it was by means of examinations. If that was considered such a great point, surely they ought to give the Colleges that had provided the training some recognition, whereas the Council had confined the benefit to only a few. He suggested to the Council that there were many Colleges quite equal to those mentioned in the list from the point of view of the training of mechanical engineers. For instance, there was his own College—Finsbury. Of the last four Secretaries of the Graduates' Association three had been Finsbury men, and at one time not very long ago half of the Committee was composed of Finsbury men. Although the Finsbury College was not mentioned in the Draft, he presumed it was covered by the City and Guilds College, because Finsbury was now the Engineering College of the City and Guilds College.

The Chairman called Mr. Smith's attention to the fact that the Draft did not purport to be a complete list at all. Enquiry had simply been made in each case, and the examination papers had been published. Mr. Smith must not regard the Draft as a final document.

Mr. Smith replied that he presumed the Chairman's remarks meant that if a man applied as a Graduate and said he had passed such and such an examination, the Council then considered that particular examination; but what he asked for was that the list should be made more complete and published—the actual list itself.

The Chairman said that that would undoubtedly be done.

Mr. Smith thanked the Chairman for that assurance. In the examinations as drafted he noticed that no mention was made of an entrance fee. Were the Graduates to infer from that that the Institution did not propose holding examinations actually, and that the object was that men should qualify in their College examinations, and so forth?

Dr. H. S. Hele-Shaw (Member of Council) suggested that what the Council wanted was to get a general expression of opinion on the proposed Draft scheme, and that the Secretary of the Graduates' Association should therefore not devote his remarks too much to details, as these could be dealt with afterwards, and he ventured to think that only questions of principle should be discussed at the present Meeting. If the Meeting wandered into details of fees and syllabuses the members would gradually depart, and the Council particularly wanted a real vote one way or the other in order to know what was actually the opinion of the bulk of the members.

Mr. Smith, continuing, said the Graduates' point of view was, when would they be able to give the Council their detailed opinions? The present appeared to him to be their only opportunity.

The Chairman suggested that, with the data in front of him, Mr. Smith was not in a position to quote definite requirements.

Mr. Smith said that was the case.

Dr. Hele-Shaw said it would take a long time to discuss a number of important details, and if the Meeting could decide that evening "Yes" or "No" on the question of examinations, there would be plenty of opportunities for dealing with details later on.

Mr. Smith thought that if a letter was sent from the Graduates' Association, it would help the Council to come to a definite conclusion, and he would therefore not pursue the matter further.

Mr. J. E. G. Fryer suggested that examinations should be held, but that the Council should reserve to itself discretionary powers to exempt from them any candidate in whatever grade he was in, unless, after consideration, the Council decided that such an arrangement would give rise to possibilities of abuse. He was quite sure that the examination, legitimate as it was, would exclude

(Mr. J. E. G. Fryer.)

some useful men, simply because their daily work left them no time in which to prepare.

Mr. **Daniel Adamson** urged that the question was too important to be settled by the comparatively small percentage of the members present at the Meeting, and suggested that the whole of the membership should be consulted rather than that a resolution should be put before that Meeting.

Mr. **Alfred C. Gardner** entirely agreed with Mr. Adamson's remarks as to the desirability of canvassing the whole of the members of the Institution on such an important question. He congratulated all the members present on not having to face the ordeal of passing an examination, and felt very pleased himself that he was now in the Institution. The question of details could, he thought, be safely left to any Committee that the Council chose to appoint, provided they submitted to the whole of the members of the Institution, as they undoubtedly would, the result of their investigations and their finding. The question for the Meeting was: Was the Institution to have an examination or not? And he thought the majority of the members were in favour of it. The present was the first serious attempt that had been made to raise the status of the Institution of Mechanical Engineers. He thought that the discussion of details should be left to some future occasion.

Mr. **H. Norman Davey** desired to be allowed as a Graduate to make a few remarks on the nature of the examination. It had been said that the object of the examination was to raise the status of the candidate who passed it, by which he presumed was meant his status as an engineer. That raised the question of what was an engineer? If the Institution was going to raise the status of a candidate who desired to be an engineer, it was necessary to be quite sure of what was meant by the term "engineer." An engineer was not a scientist only nor a business man only; he was both. So far as the syllabus of the examination was concerned, he thought the economic side had been a little neglected, because after all there was only one object which an engineer could ultimately fulfil, and that object was economy. The object of an engineer was to obtain the maximum benefit at the minimum cost, and the same principle applied everywhere, using the terms—benefit and cost—in their widest sense. In fact it might be said that the engineer should be versed in the management of men, firstly; of money, secondly; and of machines, thirdly. He suggested that there should be added to the scientific syllabus a Paper on Economics, the questions dealing with balance sheets, first costs, management, and so forth.

The Chairman said he did not imagine the members would expect him to go over all the points which had been raised, but he would refer to a few of them. Mr. Hunter referred to the combination, and so forth, of the different parts as set out in the draft scheme. Personally he thought it ought to be made perfectly clear that, though the draft was headed an Examination for *Associate Membership*, it did not by any means follow that that might not begin with the Graduates; in which case he took it that Part (A), which Mr. Hunter said should be expanded, would naturally be expanded; but he thought it would also probably have to include (B); at any rate it should be possible for a Graduate to take (A) and (B) at the same time. Section (C) would be of more importance perhaps, because it applied to the man who had slightly more experience. He thought it was necessary that he should accentuate that particular point, because in the resolution which he began to read in his previous remarks, and which he deliberately did not finish reading, he had endeavoured to cover that particular point, leaving the question somewhat open.

With reference to Mr. Adamson's suggestion that the Meeting was a comparatively small one to deal with a subject of such magnitude, he could only say that neither the Council nor the Institution had any other means of proper action than had been done in the present case, that it was by including, after giving due notice, the subject for consideration at the Annual General Meeting. All the members had received a notification of the

(Sir H. Frederick Donaldson, K.C.B.)

suggested scheme, because a copy of the Annual Report had been sent to each member, and the Council would be very glad indeed if the members would take the trouble to give the Council the benefit of their opinions, whether they agreed or disagreed with the suggestion. That could not but help and strengthen the hands of the Council, and he believed the Institution also. He therefore asked permission to move the following resolution, which he hoped for the well-being of the Institution the members would pass, because it was a necessary step to take before the Council could actually make any further progress :—

"That this Meeting generally approves the proposal that each Candidate (of an age at present fixed at thirty years and under) for class up to Associate Membership should (in addition to requirements embodied in the present By-laws) afford satisfactory evidence of training, either by suitable educational tests or by passing an examination initiated by the Council on behalf of the Institution; and that the Council be requested to draw up any alterations in the By-laws which may be necessary, for submission to the members at a future Meeting."

In connection with the last sentence, he would like to make it clear that on another occasion when the altered By-laws, which would have to be passed at an Annual General Meeting, came up for approval, the subject which caused the need for alteration could be open for discussion again if anybody wished to raise any points; and it was also to be hoped that the scheme would then have ceased to be, as it only purported to be at the present time, a draft scheme, and would be a scheme in detail which members of the Graduates' Association would certainly have an opportunity of discussing between themselves, so that their combined wisdom might be brought to bear upon the Council.

Mr. EDWARD C. R. MARKS said he seconded the motion with great pleasure. The point was one on which he differed from Mr. Adamson. Personally, he agreed that something should be done. He had listened very attentively to everything that had been said by the various speakers, and, provided the examination was of the right type, he thought it was something from which the younger men should not shrink. He was amused by the remark of one of the speakers who said that he supported the proposition because he was already inside the Institution. Personally, he supported it, because all that those gentlemen who had the engineering instinct but did not like examinations were asked to do, was to wait until they were thirty and then apply on their merits to the Council. He understood from what one of the Graduates had said that they wanted to remain Graduates till they were thirty years of age, which would be a fair slice out of their lives. He felt, however, that although the question was an intricate one, something should be done to lift the status of the Institution of Mechanical Engineers up to that of the other Institutions, and he was convinced that no better plan for doing that could be thought of than of having examinations for the younger men. Many of the members felt very strongly that the door of the Institution had not been guarded as carefully as it might have been. There was a danger in that direction at present, which he felt would be avoided by the Council's suggestions. The Council would have power to recommend a man for election, after he had reached the age of thirty, who was not able to pass an examination. He quite agreed that there were some excellent men who could not pass an examination; in fact he was certain that many of the present Members could not do so. That, however, was not an argument that a young man before he entered the Institution should not pass an examination. He seconded the motion with great pleasure.

The resolution was then put and carried, there being only one dissentient.

Communications.

Mr. H. H. **Broughton** wrote that he was of the opinion that those Colleges which held their own examinations should be recognized. Without doubt there was something wrong in admitting the Professors at those Colleges to the Institution if they could not be trusted to give an opinion on a candidate's academic qualifications. He thought that it was a mistake not to hold a Graduates' Examination. The best time for holding an examination on General Knowledge and General Scientific Knowledge was the time immediately after the candidate had left school and immediately before he had started to specialize. Although the syllabus which had been suggested was a wide one, he believed that it would be a good thing to include in that syllabus the Theory and Design of Structures. In many branches of mechanical engineering a wide knowledge of the subject was demanded. Many of them knew to their cost that many of the breakdowns of electrical machinery were due to faulty mechanical design, and he asked the Council to make the section on Machine Design sufficiently wide to include the mechanical design of electrical machinery. It was with regret he noticed that the proposed examination was largely academic. Was it not equally important to inquire into the needs of the practical engineers ?—of the men who made and sold things ? After all, the prosperity of the Institution depended entirely on the ability of its members to buy materials; to make machines; and to sell them. In view of that, he suggested that Estimating and Works Management should be included in the syllabus as optional subjects. If the scheme were carefully considered before it was put into execution, he was confident that it would mark the commencement of a new era in the history of the Institution; an era of which the members would have every reason to be proud.

Mr. **HUGH CAMPBELL** wrote that the proposed scheme of examination for entrance to the Institution did not meet with his approval. He did not think that anyone could say that the present candidates were inferior to the older men, or that there was any likelihood of a scarcity of good men coming forward to support the Institution. He was of opinion that examinations were totally inadequate for testing or proving the capacity of a man as an engineer, and he failed to see what was to be gained by enforcing examinations, except to produce men crammed for the occasion of passing. The Institution had been built up by men of whom the country was proud, but who undoubtedly would have failed to pass examinations.

Professor **E. G. COKER**, D.Sc., wrote that he was wholly in favour of an educational test, but it appeared to him that if a system of examinations by written Papers came into force, it would do more than anything else to bring into existence a number of professional crammers, who would no doubt be eminently successful in showing their clients how to pass written examinations. This was not what the Institution wished to bring about, but it was difficult to see how such a state of things could be avoided, unless the Institution recognized in a very comprehensive way the diplomas and certificates of proficiency given by existing colleges of engineering to their students, or the certificates of public examining bodies like the Board of Education and the City and Guilds of London Institute. He wished especially to draw attention to the fact that there were a number of engineering colleges in this country, not connected with Universities, which had been equipped with fine Engineering Laboratories and adequate staffs of teachers at great initial cost and large annual expenditure. It would be quite easy to mention several where £50,000 and more had been expended in buildings and equipment, and £10,000 a year in maintenance. If such Engineering Colleges were not recognized by the Institution, it would lower their prestige and otherwise do them harm. It would be unfair to ignore the training which such colleges provided, as it was in many cases of quite as high a standard,

(Professor E. G. Coker, D.Sc.)
and bore quite as directly on real engineering, as a course which ended in a degree.

Mr. Henry Darling wrote suggesting that in the draft subjects, Part C, Technical Knowledge, three Papers instead of two, as proposed, be selected for examination.

Mr. Walter Dixon wrote that he objected to the proposed scheme of examinations. If the object were to prevent undesirable candidates from entering the Institution, he thought that a Sub-Committee of the Council could deal far more effectively with the matter. With regard to examinations, he thought that by the time an engineer was twenty-six and upwards he was too concentrated in the line in which he wished to specialize, and would not have the time to study subjects not immediately concerned with his special branch of engineering. The result would be that specialists would be precluded from joining the Institution. A further objection to the proposal was that he thought the professorial element would be brought into the active working of the Institution, which in his opinion was undesirable.

Mr. A. H. Hall wrote that, in his experience, the possession of a fair aptitude for mathematics and the knowledge to cram would in a general way enable a candidate to pass engineering examinations without any real knowledge of the subject. He suggested that books might be allowed to the candidates, at any rate for the Technical Knowledge subjects, and, if possible, for Physics and Chemistry. The knowledge of formulæ was generally unimportant in engineering work, but the ability to find what was required and the knowledge how to apply it correctly when found was all important. It was notorious at one time that the boys from Public Schools who passed into Woolwich were better equipped than those from the crammers, the latter taking the subjects that could best be crammed, while the former were prepared in alternative subjects that were more educative; and, with exceptions of course, the Public School boys were of a higher mental calibre, and usually gained in the subsequent examinations. In order to avoid this difficulty, he suggested that the Technical Knowledge subjects should be subdivided into two headings, and that it should be obligatory to select one subject under each heading, as the chance of cramming two similar subjects could thus be minimized. He also suggested for consideration whether it might not be possible, as an alternative to the examination, to allow a candidate in the first place to write a thesis on some engineering subject, of which the scope should be interpreted as widely as possible, and the standard to qualify by this means should be high. Should the candidate fail to satisfy the examiners by this means, the examination should be compulsory.

Mr. W. E. **Pritchard** wrote suggesting that, if examinations were introduced, they should be of University standard.

Mr. **Robert Royds** thought the scheme was a step in the right direction, provided that the Examination did not become a mere reproduction of ordinary College or University Examinations for an Engineering Degree. He noticed that among the syllabuses for examination in Technical Knowledge there was no mention of air-compressors, air-driven tools, fans, blowers, and heating and ventilation plant, and suggested that these might form an additional section, unless it was found that they could be conveniently included in one of the other sections; also he thought more emphasis should be laid on the testing of plant, so as to include internal-combustion engines, hydraulic machinery, fans, etc., as well as steam and the steam-engine C (*b*); and to carry out this emphasis he suggested that the following clause be added to the conditions of the examinations in Technical Knowledge: "In sections (*b*), (*c*) and (*d*) two compulsory questions will be set relating specifically to the testing of plant."

Mr. J. H. **Sams** wrote that it seemed to him that one class of Mechanical Engineers had not been considered in the draft of the Examination Subjects. He referred to the Commercial Engineer,

(Mr. J. H. Sams.)

the engineering representative or traveller. He regarded a commercial engineer as one who had served his apprenticeship in the works and had some experience of the drawing office; who had had some subsequent practical experience and a good general knowledge of machinery of many kinds and for many purposes; who could tell his principals if a new kind of machine was required, and what kind of machinery was required for any special purpose in the countries he visited; and who could speak one or more foreign languages. This type of engineer was often gradually developed. A young engineer apprentice, who had shown himself capable in the shops and who had the advantage of knowing some foreign language, was selected for the erection or working of some machinery abroad. If, in addition to carrying out successfully mechanical work entrusted to him, he possessed and used any commercial instincts, he might be able to give his principals much useful information, with the probable result that he would be again and again employed on similar missions. Thus he grew into the position of representative or commercial engineer. His frequent absences deprived him of any advantages that might be gained by continuous workshop practice and by continuous theoretical studies in engineering colleges. In an examination, as a test of theoretical knowledge, he would be at a disadvantage with young men of equal age who had been continuously studying in engineering classes. He thought it was admitted that the English were not, as a rule, as good linguists as some foreign competitors, and he would have been glad to see some mention of this useful knowledge in the scheme of subjects for examinations.

Suggestions as to Examinations to place upon the Exempting List :—

City and Guilds Engineering College, South Kensington, three years' course.

City and Guilds of London Technical College, Finsbury, two years' course. (Dr. Coker.)

Naval Engineers :—

Membership : Eight years' seniority as Engineer Lieut.

Associate Membership : Recognized course of training on H.M.S. "Marlborough," or at the Royal Naval College, Keyham, and at least one session at the Royal Naval College, Greenwich.

Graduateship : Lieutenants (E.). (Eng. Commander A. E. Tompkins, R.N.)

Associate Member Examination of Inst. C.E. (L. W. Blanchard, *G*.)

Several other Communications were received subsequently and included the following suggestions :—

Lieut.-Col. C. T. **Bell**, R.A., of the Gun and Shell Factory, Cossipore, wrote appreciating the Council's scheme, and noting approvingly that it was not intended to insist on senior candidates passing an examination. He thought it would be well to insist upon a paper or thesis from *all* candidates for membership (including Associateship), and hoped that eventually a General Engineering Council might be formed to issue licences to practise Engineering, somewhat on the lines of the General Medical Council.

Mr. E. G. D. **Fawcett**, on behalf of himself and some other Graduates, wrote that a man who served his time in works had neither the time nor the inclination to work up for an examination in Physics and Chemistry. He suggested that Steam and the Steam-Engine or Theory of Machines and Machine Design might be made compulsory subjects in their stead.

Mr. Percy Griffith wrote that the multiplication of examining bodies was becoming a serious inconvenience and rather detrimental than otherwise to the status of the engineering profession. He thought, however, that admission for the younger men should be by examination, such elementary examinations being standardized in combination with other engineering institutions; and he would prefer that efforts should be made to unify the many competing examinations which were now established. In regard to the examination of more advanced candidates for full Membership in the consulting branch of the profession, he thought some attempt should be made to standardize the tests of experience and ability.

The Institution of Mechanical Engineers.

PROCEEDINGS.

March 1912.

An Ordinary General Meeting was held at the Institution on Friday, 15th March 1912, at Eight o'clock p.m.; Sir H. Frederick Donaldson, K.C.B., Vice-President, in the Chair.

The Chairman said that, before proceeding to business, he had to announce with regret the decease of Mr. Thomas P. Reay, Member of Council. Mr. Reay had been a Member of the Institution since 1882, and had been a Member of Council since 1906. The Council had that day passed a resolution of condolence with his relatives, and a letter to that effect was being despatched.

He also wished to express the regret of the President at being prevented, by doctor's orders, from presiding that evening at so important a Meeting. The President was confined to the house and it was a matter of great personal regret to him, as it was to the Council and to the members, that he was absent.

The Minutes of the previous Meeting were read and confirmed.

The Chairman announced that, to fill the vacancies among the Members of Council, caused by the election of Dr. W. Cawthorne Unwin as a Vice-President and the decease of Mr. Thomas P. Reay, the Council had appointed Mr. Donald B. Morison and

Mr. William H. Patchell as Members of Council. They would retire at the next Annual General Meeting, in accordance with Article 25.

The Chairman announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and that the following eighty-eight candidates were found to be duly elected:—

MEMBERS.

Allen, Claude,	London.
Angus, James Allan,	Rangoon.
Appleyard, Frederick,	West Hartlepool.
Barry, David,	Purfleet, Essex.
Barsdorf, Henry,	Manchester.
Birks, Lawrence,	Wellington, N.Z.
Black, George James Forbes,	Burton-on-Trent
Buckley, Samuel,	Sheffield.
Burton, Thomas Bowman,	Manchester.
Crighton, Charles,	Negapatam.
Cunningham, John Cunningham,	Broken Hill, N.S.W.
Goodwin, George Goodwin, Engineer Captain, R.N.,	London.
Harding, Wallace Alan Douglas,	Huelva.
Harrop, Frank Harold,	Alfreton.
Hill, Joseph Albert,	Sheffield.
How, Thomas William,	London.
Jones, Frederick Monkhouse,	Weymouth.
Kempe, Harry Robert,	London.
Kidd, Fred,	Astillero, Spain.
Kirkwood, James Emmett,	Belfast.
Lister, Francis Henry, Engineer Commander, R.N.,	London.
Livsey, Harold,	Leeds.
Moore, William George,	Birmingham.
Sayer, Arthur Edward,	Birmingham.

Stephenson, Arthur Henry,	Cape Town.
Teed, Henry Richard, Eng. Commander, R.N.,	London.

ASSOCIATE MEMBERS.

Angles, John William,	West Hartlepool.
Atkinson, Reginald Charles,	Folkestone.
Avila, John Frederick,	London.
Beale, Frederick,	Calcutta.
Bergin, John James,	Athy, Co. Kildare.
Brown, Bertram Hugh,	London.
Bruce, David Colville,	Bahia Blanca.
Carnegie, Ebenezer,	Hayes, Middlesex.
Chowna, Pallonji Dadabhoy,	Bombay.
Earnshaw, William,	Wellington, N.Z.
Hawkins, Hervey Carleton,	Clydach, Glam.
Hinde, William Johnson,	Shipley.
Horn, Bertram,	Stockport.
Huddleston, George Reginald Graham,	Jamalpur.
Hutson, Charles Arthur,	Colombo.
Ingham, Edward,	Manchester.
Isaac, Morris Templeman,	Portmadoc.
Jefferiss, Harold Edward,	Birmingham.
Kendal, Arthur Barnhart,	Wellington, Salop.
Kendall, Alfred Harold,	London.
Kent-Norris, Henry, Jun.,	Newbury.
Leek, Albert Edward,	Tipton.
Le Pla, Frederick Gwilym Robertson,	Clydach, Glam.
Lydall, Charles Hawthorne,	Newcastle-on-Tyne.
McFee, William Morley Punshon,	London.
Mason, Herbert Richard,	Erith.
Milward, William Francis,	Lowestoft.
Moore, Edward Stapleton,	Exmouth.
Murray, William Robert,	Ayr.
Myers, Archibald Charles Tracey,	London.
Nunn, Harry Vaughan,	Bradford.
Price, Francis Longueville,	Stamford.

Schultz, George Christopher,	Skipton.
Strachan, James Alexander Pierson,	Bangkok.
Taylor, William Thomas,	São Paulo, Brazil.
Thorne, Douglas Stuart,	London.
Troughton, Henry James,	London.
Watson, Henry Archibald,	Glasgow.
Webb, Herbert Arthur,	Woolwich.
Yates, Reginald Cholmeley Campbell,	Perambur, India.

GRADUATES.

Aslett, Edward Stratton,	Bristol.
Benny, Herbert Berger,	London.
Bentley, Hubert,	Halifax.
Brodie, Edward David,	London.
Corfe, Allan William,	Wallasey.
Davison, William,	London.
Domleo, Robert Frearson,	Breaston, Derby.
English, John,	Warrington.
Franklyn, Francis Edward Hazelwood,	London.
Gale, Thomas James,	London.
Hickling, Frank,	London.
Lauder, Robert Bruce Douglas,	Manchester.
McQuaigue, Frederick Ernest,	London.
Manico, Edward Leslie,	Lahore.
Mason, James Wardley,	Manchester.
Moore, John Leslie Mackenzie,	Canterbury.
Neilson, Archie McNicol,	Paisley.
Peace, Archibald Gilchrist,	Liverpool.
Robb, Harold Brindley,	London.
Robinson, Cecil Joseph,	Widnes.
Temple, George Lee,	London.
Wardle, George Eyre,	Chester.

The CHAIRMAN announced that the following nine Transferences had been made by the Council:—

Associate Members to Members.

CROSS, WILLIAM MARK,	Birmingham.
HAMBLY, PERCY NOEL,	London.
JACKSON, JOHN WILLIAM,	Wallsend-on-Tyne.
KNOWLES, LEONIDAS,	Manchester.
LAMBERT, JOHN HENRY,	Negapatam.
MONTGOMERY, CHARLES HUBERT,	Rosario de Sta. Fé.
REEVE, ROBERT JOHN ROBEY,	London.
ROBERTS, HENRY JAMES,	Port Talbot.
WATSON, GEORGE WILLIAM,	London.

The following Paper was then read and discussed:—

"The Diesel Oil-Engine, and its Industrial Importance, particularly for Great Britain"; by Dr. RUDOLPH DIESEL, of Munich.

The Meeting terminated at a Quarter past Ten o'clock. The attendance was 359 Members and 357 Visitors.

THE DIESEL OIL-ENGINE, AND ITS INDUSTRIAL IMPORTANCE, PARTICULARLY FOR GREAT BRITAIN.

BY DR. RUDOLPH DIESEL, OF MUNICH.

[*Translated from the German.*]

There have been so many publications recently, and especially during the past year, in technical periodicals of all languages, on the construction of the Diesel engine and its various types, that it is hardly possible to give any fresh information on the subject. Moreover, an excellent Paper was read only last summer at the Zürich Meeting of the Institution by Mr. J. F. Schubeler. The author proposes, therefore, to discuss only questions of general importance concerning the Diesel engine, especially those questions which are brought into prominence in the title of the Paper, and to consider them only as the starting point of a thorough and stimulating discussion. He desires, further, to be exonerated if statements are made in the Paper on points which are common knowledge.

Since its first appearance about fourteen years ago the Diesel engine has been built by the thousand in the best factories of all industrial countries, and has been set up in the most remote corners of the world. It has been proved to be a most reliable engine when properly built, the working of which is quite as safe as that of any other system of prime mover; and in general it is even more simple, since it does not require any auxiliary apparatus, and since the fuel in its natural and original form, without having previously undergone any transforming process, is directly converted into work in the cylinder of the engine. As early as 1897, when, after four years of difficult experiments, the author had put the first engine into working order in the factory of the Augsburg Works, numerous engineering representatives and experts who came from various countries to examine this engine expressed the opinion that it gave better heat utilization than any known kind of heat engine. From experience gained subsequently by working many engines, by gradual improvements in the construction and manufacture, and by increasing the size, the results have been still further improved, and to-day the thermal or indicated efficiency reaches 48 per cent.* in this engine, and the effective or brake efficiency reaches, in some cases, 35 per cent. of the heat value of the fuel.

Fig. 1 shows the heat utilization for 1 b.h.p.-hour in the different kinds of prime movers known to-day. Science and technical knowledge are making continuous progress, and the time will come when even these figures will be exceeded; but, with our present scientific knowledge, any considerably higher efficiency in the process of transforming heat into mechanical work is not obtainable. Further progress seems only possible with some other method for transforming heat into work; this would mean an entirely new principle, which, however, one cannot speculate upon in the present state of science.

The Diesel engine is therefore the engine which converts the heat of the natural fuel into work in the cylinder itself, without any previous transforming process, and which utilizes it as far as the present standard of science permits; it is therefore the simplest and, at the same time, the most economical prime mover.

These two facts explain its success; it lies in the new principle of the internal working process, and not in constructional improvements or alterations of older types of engines. There is no doubt that the careful working out of all the constructional details also plays a great part in the practical success of the Diesel

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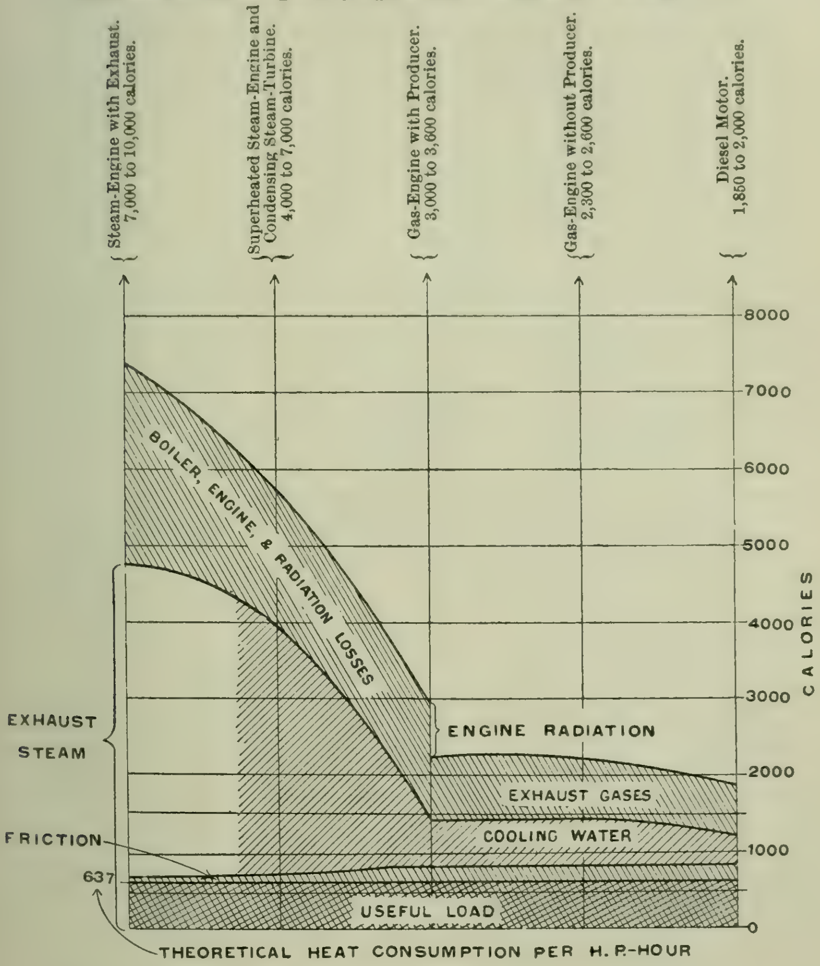
* *See* Mr. Dugald Clerk's remarks (page 236).

Fig. 1.—*Heat Consumption of different Heat Engines per B.H.P.-hour.*



engine, as in any other; but they are not the essential points, and above all they do not constitute the great importance of this engine to the world's industry.

A further reason for this importance is that the Diesel engine has broken the monopoly of coal, and has solved the problem of using liquid fuel for power production in its simplest and most general form. It has become for all liquid fuels what the steam-engine and gas-engine are for coal, but in a much simpler and more economical way. The truth of this statement was strikingly proved at the Turin Exhibition of last year. At this Exhibition, in the large Machinery Hall, a steam-turbine and a large Diesel engine, both made by Franco Tosi, of Milan, and set up on the same stand, were worked together with the same liquid fuel. The boilers belonging to the plant were fitted with Körting nozzles for burning crude oil. The difference between the two plants was therefore this: for the working of the steam-engine the whole boiler plant with its chimney, fuel supply apparatus, purification plant for feed-water with feed-pumps, extensive steam-pipes, condensation plant with water-pumps and an enormous water consumption, had to be provided, with the final result of consuming 2½ or more times the fuel per horse-power required by the Diesel engine standing beside it. The latter, being an entirely independent engine without any auxiliary plant, took up its crude fuel automatically and consumed it direct in its cylinders without any residue or smoke. A better proof can hardly be imagined, even for the non-technical man, that except in special cases the steam-engine cannot compete economically with the oil-engine, and from this point of view the power-plant in the Machinery Hall at Turin must be looked upon as marking a historical event. It is hardly possible for a country which produces no coal, like Italy, to develop a great industry based on the steam-engine, and this is one reason for the exhibition at Turin of about thirty Diesel engines of various types and sizes, and made in different countries.

Thus the Diesel engine has doubled the resources of mankind as regards power-production, and has made new and hitherto unutilized products of nature available for motor power. The Diesel engine has thereby exercised a far-reaching influence on the liquid-fuel industry, which is at the present time improving

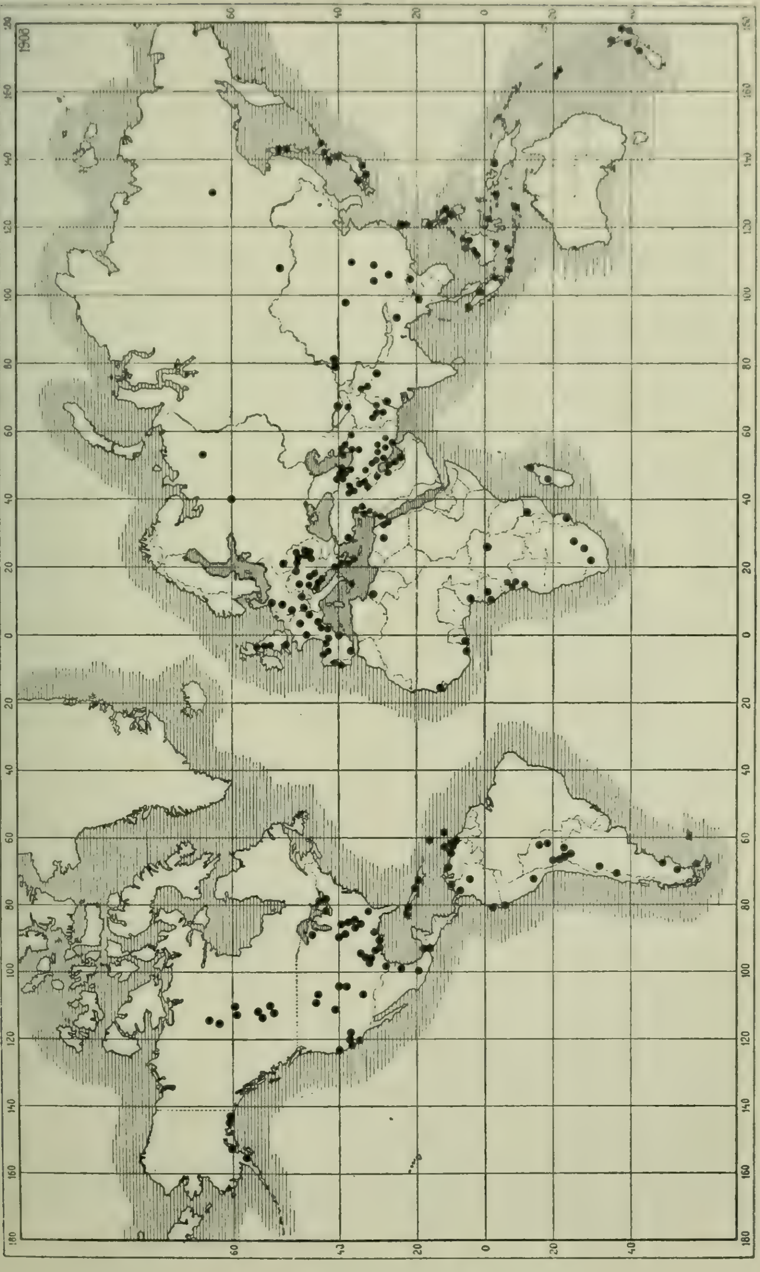


FIG. 2.—*Map showing Petroleum Fields of the World in the Year 1908.*

more rapidly than was previously conceivable. This is not the place to discuss the matter in detail, but the author wishes to mention that, owing to the interest which petroleum producers have taken in this important question, new petroleum sources are continually being developed, and new oil districts discovered. Moreover, it has been proved by recent geological researches not only that there is probably on the globe as much, or perhaps even more, liquid fuel than coal, but also that it is more conveniently distributed as regards its geographical position, Fig. 2. These facts, which are indisputable nowadays, have gradually silenced those who objected to too great a development of the Diesel engine for fear of insufficient stores of liquid fuel. Any such anxiety may be relieved by the fact that the world's production of crude oil increases at present 3½ times more quickly than the production of coal, and that the ratio of increase itself is steadily getting higher. Further, that 40 per cent. of the present production of mineral oil is already sufficient to supply the whole of the naval and mercantile fleets of the world with power, if they were worked by Diesel engines; also that with the world's present production the number of Diesel engines now working could be increased about a hundredfold.

It may thus safely be asserted that, with the continual development of new oil-districts, the production of mineral oil will increase much more quickly than the demand for newly-built engines. It is therefore not surprising that, in the last yearly report of the Shell Transport Co., attention was called to the fact that the oil consumption in these engines did not nearly equal the production, and that the company has to look out for other markets to dispose of their superfluous stock. That the auxiliary industries of petroleum production are also considerably influenced is shown by the great increase which the transport industry for liquid fuel has experienced in recent times, especially the great development of tank-vessels which are, or will be, mostly driven by Diesel engines.

But with all this, the influence of the Diesel engine in the world's industry is not exhausted. As early as the year 1899 the author utilized in his engine the by-products of coal distillation and coke plants, such as tar and creosote oils, with the same satisfactory results as with natural liquid fuels, but at that time the quality of these oils was generally too inferior for their use in the Diesel engine, and it was, moreover, subject to continual variations.

The difficulties were then chiefly the following:—

(1) Muddy deposits of solid hydrocarbons, especially naphthalenes, which made the working of the fuel pumps difficult, filled up the pipes and nozzles, and formed a hard crust at the nozzle mouths. These solid hydrocarbons also made higher ignition temperatures necessary.

(2) Continuous change in quality and composition of the crude, uncleaned tar-oils; with each cask fresh variations appeared even in cases where the works guaranteed the use of the same coal, and the carrying out of the same distilling process, so that it was impossible to make scientific observations for drawing any definite conclusions, or making logical experimental arrangements. The characteristics of crude tar-oils were not then exactly known even to the producers; for instance, nobody imagined that differences in the distilling temperature and variations in the nature and position of the retorts gave entirely different tar-products even when the same coal was used. It is only in recent years that the chemical industries interested in the matter have, by improved methods of fractioning and refining, combined with more careful selection of the material, succeeded in supplying fuel of a constant and regular quality, without the drawbacks of the crude tar-oils used previously. These products—the tar and tar-oils—are thus to-day definitely brought into the sphere of activity of the Diesel engine.

In Appendix I (page 208) is given a Table showing the application of various fuels for Diesel engines, while Appendix II (page 210) contains specifications for tar-oils for Diesel engines, and Appendix III (pages 212–5) gives the properties of tar.

From what has been just stated, it will be seen that the Diesel engine is having an increasing influence on two other industries—the manufacture of gas and coke—the by-products of which have become so important for power production that an enormous business is at present connected with them.

It is especially noteworthy that every town gas-works with a modern installation, and every coke-works, can be completed with an electric power generating plant by using its tars. This will have an excellent effect on many municipal and national works. It would take too much time to enter into the details of this question, but one fact stands out clearly in this connection, namely, that coal, which seemed to be most threatened by the liquid fuels, will, on the contrary, gain a new and wider ground of application through the Diesel engine. As tar and tar-oils are from 3 to 5 times better utilized in the Diesel engine than coal in the steam-engine, a much better and more economical utilization of coal is obtained if, instead of being burned under boilers on grates in a wasteful way, it is first transformed into coke and tar by distillation. Coke is used in metallurgical and other general heating purposes; from a part of the tar the valuable by-products are first extracted, and undergo further processes in the chemical industry, whilst the tar-oils and combustible by-products, and a great part of the tar itself, are burned in the Diesel engine under extraordinarily favourable conditions.

The proper development of the utilization of fuel, which has already been started, and is now making rapid progress, is therefore the following: On the one hand liquid fuel in Diesel engines, and, on the other hand, gas fuel also in the form of gasified coke in the gas-engines; solid fuel as little as possible for steam-power generation, but only in the refined form of coke for all other heating and metallurgical purposes.

The list of fuels applicable to the Diesel engine is not, however, exhausted with these liquid fuels mentioned previously. It is known that brown coal or lignite, the production of which is about 10 per cent. of the pit-coal production, also yields tars by distillation, and these tars when distilled, and worked up on paraffin, produce the so-called paraffin oils as by-products. Not all kinds of brown coal, however, are suitable for this process; but, in any case, these oils have been produced in such quantities that so far they have satisfied a good part of the German demand for liquid fuels for Diesel engines. To these must be added other products, such as shale and similar oils—produced not in great but in sufficient quantities to be of importance for power generation. Some countries—France and Scotland for instance—possess them in considerable quantities, and they are used in a good many Diesel engine plants. It is not generally known that it is also possible to burn fat vegetable oils and animal oils in the Diesel engine without any difficulty.

At the Paris Exhibition in 1900 there was shown by the Otto Company a small Diesel engine which, at the request of the French Government, ran on Arachis-oil,* and worked so smoothly that only very few people were aware of it. The engine was constructed for using mineral oil, and was then worked on vegetable oil without any alterations being made. The French Government at the time thought of testing the applicability to power production of the Arachide or earth-nut, which grows in considerable quantities in their African colonies, and which can be easily cultivated there; because in this way the colonies could be supplied with power and industry from their own resources, without being compelled to buy and import coal or liquid fuels.

This question has not been further developed in France owing to changes in the Ministry, but the author resumed the trials a few months ago. It has been proved that Diesel engines can be worked on earth-nut oil without any difficulty, and the author is in a position to publish, on this occasion for the first time, reliable figures obtained by tests:—Consumption of earth-nut oil, 240 grammes (0·53 lb.) per b.h.p.-hour; calorific power of the oil, 8,600 calories per kg. (15,480 B.Th.U. per lb.), thus fully equal to tar oils; hydrogen, 11·8 per cent. This oil is almost as effective as the natural mineral oils, and as it can also be used for lubricating oil, the whole work can be carried out with a single kind of oil produced directly on the spot. Thus this engine becomes a really independent engine for the tropics.

Similar successful experiments have also been made in St. Petersburg with castor-oil; and animal oils, such as train-oil, have been used with excellent results. The fact that fat oils from

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* Earth-nut or pea-nut—botanical name *Arachis hypogaea.*

Working Diagrams of Single-acting Diesel Engines.

FIG. 3.—*Four-stroke Cycle.*

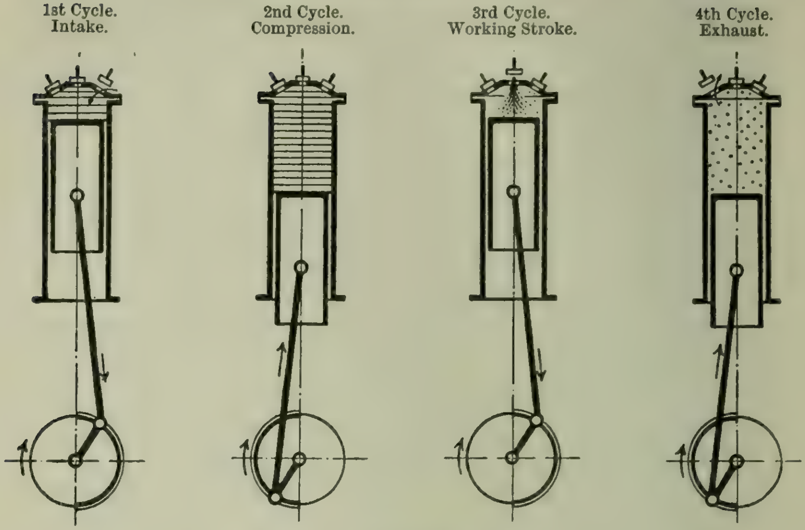
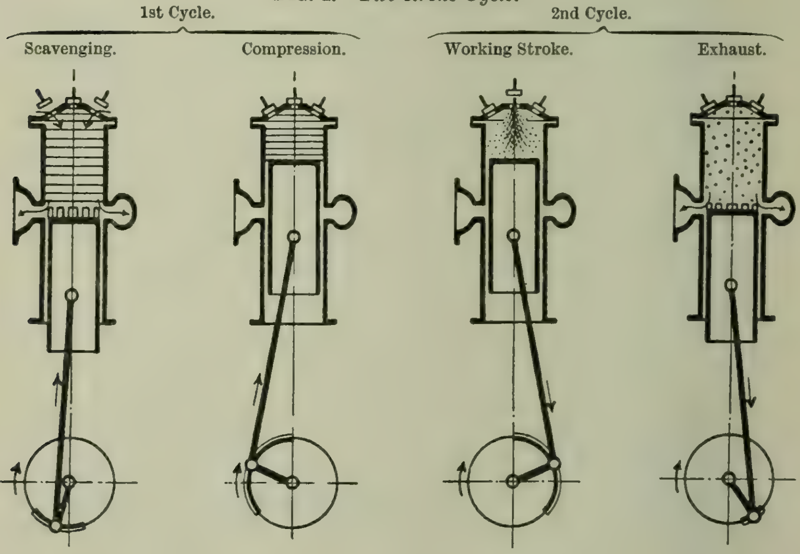


FIG. 4.—*Two-stroke Cycle.*



▤ 1. Inlet of pure air.

▤ 2. Compression of pure air.

▨ 3. Combustion and Expansion of the sprayed engine oils.

▨ 4. Expulsion of the gases of combustion.

vegetable sources can be used may seem insignificant to-day, but such oils may perhaps become in course of time of the same importance as some natural mineral oils and the tar-products are now. Twelve years ago the latter were not more developed than the fat oils are to-day, and yet how important they have since become.

One cannot at present predict what part these oils will play in the colonies in the future. In any case, they make it certain that motor power can still be produced from the heat of the sun, which is always available for agricultural purposes, even when all our natural stores of solid and liquid fuels are exhausted.

HISTORICAL SUMMARY.

The author thinks that a summary of the whole development of the Diesel engine, and of the general points connected therewith, with illustrations of a few engines which mark stages in its evolution, may be of interest to the members. Several of these have already been published separately in the technical Press, but the series, as a whole, in its historical connection is quite new, and a certain number of the photographs have not been previously published. Figs. 3 and 4 show small illustrations of the principal movements in the four-stroke and two-stroke cycle engines, with the corresponding indicator-diagrams in Figs. 5 and 6 (page 190), because these will constantly be referred to in the Paper.*

FOUR-STROKE CYCLE ENGINE.

Vertical Stationary Engines.—The first experimental Diesel engine, Fig. 7, Plate 4, constructed in 1893, had the piston fitted with a piston-rod and external cross-head, the cylinder having no water-jacket; the cam-shaft was arranged very low, and the valves were actuated by means of long rods. The starting storage-chamber consisted of a wrought-iron pipe with riveted flanges, and there was no air-supply pump, the fuel being injected directly.

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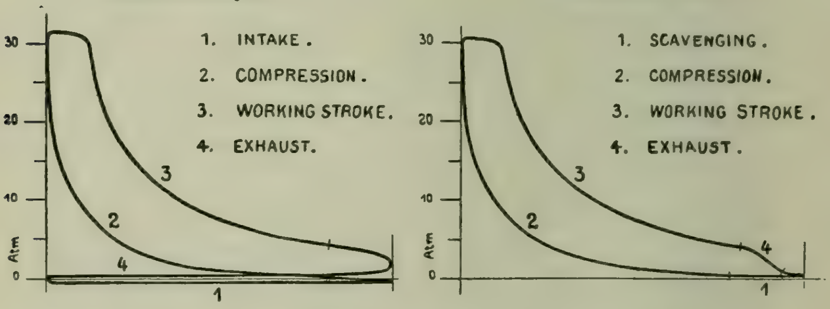
* These diagrams are taken from a publication by the Maschinenfabrik Augsburg und Maschinenbaugesellschaft Nürnberg A.G. (M.A.N.).

A later pattern, Fig. 8, Plate 4, built in 1895–96, had a similar base to that shown in Fig. 7, but it had a water-jacketed cylinder and the cam-shaft was placed higher up. But the most important difference from the old pattern was in the air-supply pump, the necessity for which was only recognized after several years' experimenting, as without it a smokeless combustion could not be effected. This air-pump is single acting, but the author previously used a special vertical compound air-pump driven from a transmitting shaft.

FIGS. 5 and 6.

Indicator Diagrams of Single-acting Diesel Engines. (Taken from original diagrams.)



Four-stroke Cycle. Two-stroke Cycle.

The first French and Belgian engines were nearly of the same type as that shown in Fig. 8, but had no air-pump; they were also of better and more compact construction.

The first reliable Diesel engine, Fig. 9, Plate 4, of 18 h.p. was finished in 1897 at Augsburg, after about four years' laborious experimenting. It was a vertical engine having the piston connected to an external cross-head and worked on the four-stroke cycle. The illustration shows the engine with the testing-brake attached, and with the other testing apparatus exactly in the state in which it was used by the numerous Commissions of engineers and experts who came from different countries to examine the engine, as mentioned earlier in this Paper. This type was for about ten years the exclusive and almost stereotyped pattern for all Diesel engines, which were built in various countries.

In the following year, 1898, the first single-cylinder engine of 20 to 25 h.p. was built at the Augsburg Works. This engine had almost all the characteristic details of the experimental engine just mentioned, the only difference being that the experimental engine had the cylinder connected to the base by an inclined column in front, whilst the later pattern had the well-known A-frame which the author employed on his first experimental engines. No further alterations have been made. The engine had still the external cross-head and guides, and the petroleum-pump was actuated by the cam-shaft in exactly the same way as in the experimental engine, Fig. 9. The air-pump was cast on the base in exactly the same way, and was driven in both cases by rocking beams from the cross-head. The lubrication of the cylinders was effected by means of Mollerup appliances, and the valve-rods, the regulator, and all the details were identical in both engines. Except for alterations in unimportant details of construction, the only changes since made were that the dimensions and the numbers of cylinders were enlarged.

The two-cylinder engine of 60–76 h.p. was made in 1899, in which all the details of Fig. 9, Plate 4, are still to be recognized. The only alteration which was made in the year 1901 was the abandonment of the external cross-head and adoption of the trunk piston shown in Fig. 10, Plate 5. A comparison of this engine with that illustrated in Fig. 9 shows that, with the exception of the omission of the cross-head, no alterations of any importance have been made. Vertical four-stroke cycle engines of from 10 to 250 h.p. per cylinder were constructed after this pattern, and units up to 1,000 h.p. were obtained by combining several cylinders. These engines ran at comparatively low speeds, from 160–200 revolutions, according to their size, and were of very heavy construction. Their weight was originally from 280 to 350 kg. (617–771 lb.) per h.p., and later from 240–300 kg. (529–661 lb.) per h.p. This type of engine was used exclusively as a stationary plant for various industrial purposes. The two-cylinder M.A.N. engine of this type of 250 h.p. or 125 h.p. per cylinder was built in 1902.

A three-cylinder engine of the same type, Fig. 11, Plate 5, was made by Sulzer Bros. in 1906. The two latter engines show a slight alteration; the petroleum-pump is driven from the vertical instead of from the horizontal cam-shaft, as was the case in the previous engines. The engines built by Sulzer Bros. and by Carels have also a rotating stuffing-box for the fuel-needle. This arrangement was first built in Sweden on the author's instructions, and worked successfully. The well-known 500 h.p. three-cylinder engine of Carels was exhibited at Liége in 1905.

The author has purposely referred to this type of engine to show that these engines, which have been built in various factories and in various countries, still remain almost an exact copy of the old experimental engine, Fig. 8. Only in America was the design simplified, or rather cheapened, from the commencement by the director of the American Diesel Engine Co., Colonel E. D. Meier. In America the engines were built without cross-heads from the beginning, an idea which, as already mentioned, was followed in the year 1901 by the European firms after the American engines with trunk-pistons had proved successful. The Americans also built from the commencement a closed base frame, and this construction, as will be seen later, has also been recently adopted in the European high-speed engines, but in a more refined and better form. Moreover, the American engines had no valves in the cylinder-covers, Fig. 12, Plate 6, but they were placed in a chamber cast at the side of the cylinder, which necessitated the fuel-needle being placed horizontally between the suction- and the exhaust-valves. Finally, the Americans, instead of driving the air-supply pump direct from the engine, always set it up independently and drove it either by a small extra engine, by a transmission shaft, or by an electric motor, in the manner in which air-pumps are now set up in many Diesel engine plants on board ship. All these alterations were made with the object of cheapening the manufacture, which is the cardinal feature in American practice.

A remarkable fact is that the first Diesel engines, built in 1897–1898, are still working, without any change in their fuel consumption;

also the first English engine built by the Mirrlees, Watson and Yaryan Co. at Glasgow, according to the author's design of fourteen years ago, is still working.

As the central electric stations took up the Diesel engine very early, the necessity for quicker running engines arose. This need, and the improvement in methods of construction and utilization of materials, caused the gradual introduction of the new quicker running four-stroke cycle engines, with speeds of from 300 up to 600 revolutions. These, however, were still exclusively vertical. The main difference in construction as compared with the first type was that the bearings of the crankshaft were connected with the cylinders by means of light steel columns instead of by heavy cast-iron A-shaped frames, so that the cast-iron pedestal of the machine became a light crank-case, relieved from great strain; in addition, the thickness of all the castings was diminished. By this means the weight of the engines was reduced to about one-fourth to one-fifth of the weight of the old types, or to about 50 kg. (110 lb.) per h.p. Engines of this kind are now built up to about 700 h.p. and are especially suitable for driving dynamos, blowers, and centrifugal pumps, and also as auxiliary engines on board large vessels, etc.

The first of these high-speed four-stroke cycle engines made by the M.A.N. had no alterations in the valves, the needle, or the gearing, nor in the driving and the position of the petroleum and air-supply pumps, etc.

In a four-stroke cycle high-speed engine, Fig. 13, Plate 6, made by Messrs. Sulzer Bros. in the year 1909 the only difference, except the box-pattern frame, between it and the arrangement of the old type consisted in the position of the air-supply pump, which was in this case fitted to one end of the engine and driven direct from the crankshaft. In a later four-stroke cycle high-speed engine of 350 h.p. made by Messrs. Sulzer Bros. in 1911 the air-supply pump was also driven from the crankshaft, but was fitted between the cylinders on the box-pattern base in a neater way. In this case also no radical alteration has been made.

These latter kinds of engines may be regarded as the final and permanent type of the vertical four-stroke cycle engine for stationary purposes, both for high and low speeds. With this and similar types the development of the four-stroke cycle engine reached a definite state of development. When in the last decade, through rapid development of the French submarines, an urgent need for a reliable submarine engine was felt, these four-stroke cycle engines were further reduced in weight by using steel and brass castings, with still thinner walls, and they have also recently been fitted with reversing gear. The author will return to this point later when discussing marine engines.

Small Engines.—This summary of the development of the vertical four-stroke cycle engine would not be complete without a reference to the small engines which have recently been built in accordance with the author's designs. Fig. 14, Plate 7, shows a complete 5-h.p. one-cylinder plant, designed in 1909, for 600 revolutions per minute with petroleum tank, starting and air admission chambers. The officially recognized consumption for this small engine is 240 grammes (0·53 lb.) per b.h.p., which is therefore not much more than with the old large engines of medium horse-power. At present the author is endeavouring to simplify and strengthen this small engine, which will then be suitable for small manufacturers and for farmers, who are not especially skilled in mechanical work.

Fig. 15, Plate 7, shows a 10-h.p. plant which is composed of two 5-h.p. cylinders of the above kind; the air-pump is driven direct by the main shaft. The cam-shaft is arranged in the lower part of the base as in automobile engines. For this construction many hints have been taken from automobile engine designs.

Horizontal Stationary Engines.—After vertical engines had solely been used for about twelve years, horizontal four-stroke cycle engines were built. The author is uncertain whether this type was a real necessity, or whether it was originally only constructed for purposes of competition to bring out something new; it is, however, not his intention to compare the merits of the two types. The first horizontal engines were practically only vertical engines laid on their sides without any independent structural innovations; all the valves were fitted in the cylinder-cover, in exactly the same way as was done in the old vertical engine, shown in Fig. 9, Plate 4. The valves were actuated by a small cross-shaft, which was itself driven by means of gears from another shaft parallel to the cylinder axis. The air-pump was fitted in exactly the same way as in the old vertical engine.

Gradually the designers freed themselves from the tradition of the vertical engine, and some details were altered in such a way that they were more suitable for the horizontal position, and a type of engine was thus obtained which is hardly distinguishable from the horizontal gas-engines, as Fig. 16, Plate 7, shows. In this engine, made by the Swiss Locomotive Works, Winterthur, the inlet-valves are no longer placed in the cover, but on the side of the cylinder as in gas-engines, and are directly driven from the longitudinal cam-shaft. A cross cam-shaft is no longer used. Only the fuel and exhaust valves are left in the cover, while the air-compressor is here arranged in another way.

These designs are to-day very often used for smaller plants of 20 h.p. and more, especially by gas-engine manufacturers, who took up the construction of Diesel engines on their own account on the expiration of the patents, and who preferred to keep to the old types of horizontal gas-engines. But the M.A.N. built such horizontal Diesel engines for very high horse-powers as double-acting four-stroke cycle engines with two or four cylinders arranged tandem. The largest engine of this kind so far is a double-acting four-stroke cycle tandem twin engine, of 1,600–2,000 h.p. or 400–500 h.p. per cylinder, with a speed of 150 revolutions per minute; this engine is working in the corporation gasworks at Halle, using water-gas tar as fuel. It was constructed on the lines of the well-known Nürnberger large gas-engine for blast-furnace gas.

TWO-STROKE CYCLE ENGINES.

As very often stated by the author, the Diesel principle is essentially suitable as a two-stroke cycle engine, because the scavenging is not done with a fuel-air mixture, but with pure air, so that not only untimely ignitions but also fuel losses are avoided, and the scavenging can be done more effectively, and with almost any quantity of air desired.

The first two-stroke cycle engines on the Diesel principle were built in 1900 and 1901 in Germany and England, after drawings made by Güldner, but without success, because these drawings still followed too closely the two-stroke cycle gas-engines, and because the constructional arrangements were unsuited to the Diesel engine.

Successful attempts to construct a two-stroke cycle Diesel engine on entirely new lines have, however, been made recently by Messrs. Sulzer Bros., of Winterthur, so that to-day this type is on a nearly equal footing with the old four-stroke cycle engine. This has been effected by working entirely on the original Diesel principle. The author says "on a nearly equal footing," because the four-stroke cycle engine still has a better combustion and a more economical fuel consumption, and is, above all, simpler in its method of working. It thus remains the standard perfect engine, and still predominates for medium-sized stationary plants up to 500 or 600 h.p. (no exact limit can be given) wherever the highest perfection and the greatest economy are desired; but engineers are now doubtful whether this supremacy will last much longer. On the other hand, the two-stroke cycle engine with its smaller cylinders has now come into favour for stationary plants of higher horse-power, and, as a marine engine, is likely to become the standard type.

Two considerably different fundamental types of two-stroke cycle engines have so far been competing. To explain the principal difference, the author shows some sectional drawings. The first fundamental type is the engine made by Messrs. Sulzer Bros., Fig. 17 (page 197), with separate scavenging pump. The second—the M.A.N. engine, Fig. 18 (page 198)—was brought out much later; in it the scavenging pump, which has an annular piston, is placed underneath each combustion-cylinder. Both engines are single-acting. The author does not wish to comment upon the advantages and disadvantages of the different types, but would leave them to be discussed. Their relative merits can only be settled by experience.

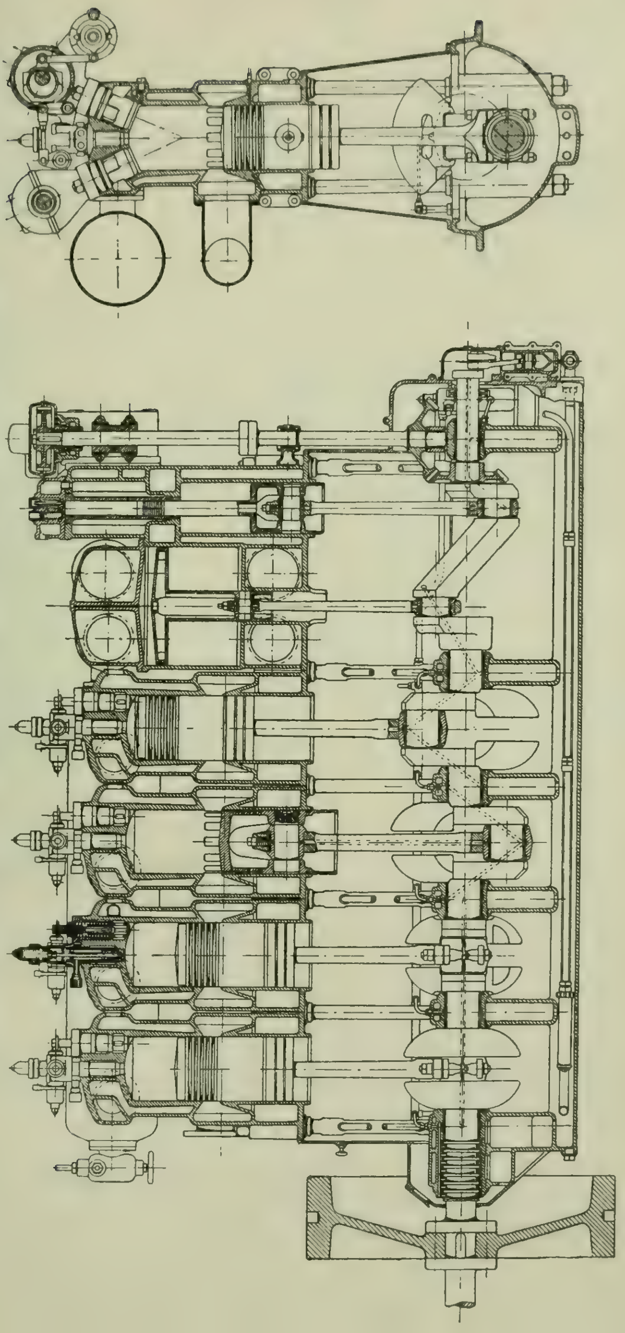


FIG. 17.

Single-acting Two-stroke Cycle Engine with separate Scavenging Pump. (Sulzer.)

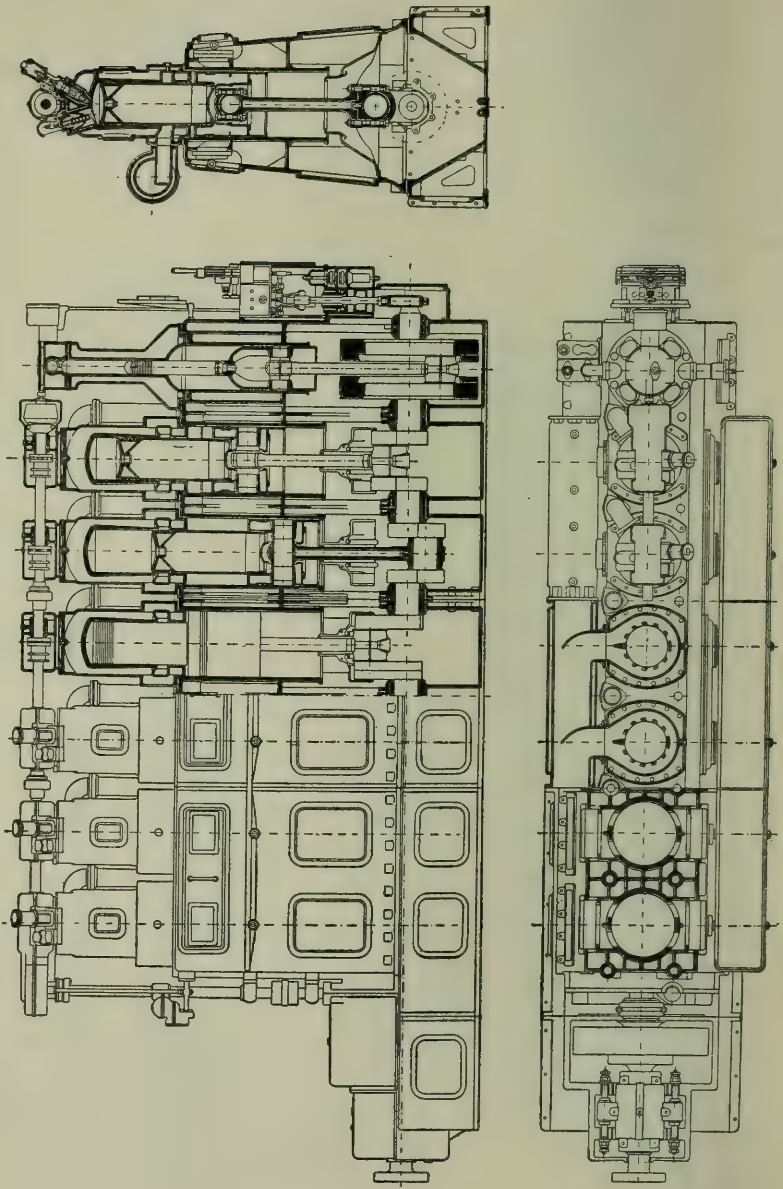
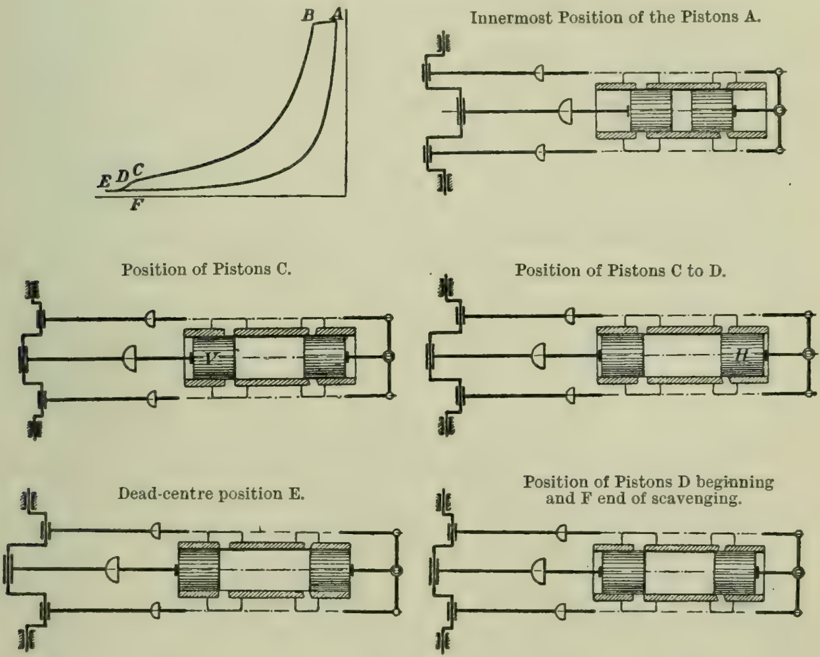


FIG. 18.—*Single-acting Two-stroke Cycle Engine with Scavenging Pump underneath Combustion-Cylinder.* (M.A.N.)

A three-cylinder 750 h.p. Sulzer-Diesel two-stroke cycle engine, and a still larger Sulzer-Diesel four-cylinder two-stroke cycle engine on the same system of 2,000–2,400 h.p., were illustrated in Mr. Schubeler's Paper read at the Zürich Meeting of the Institution last year. For such large engines two scavenging pumps are necessary. This engine has therefore an even greater power than the horizontal M.A.N. engine at Halle.

Fig. 19.

Two-stroke Cycle Single-cylinder Marine Oil-Engine. (Junkers.)



Innermost Position of the Pistons A.

Position of Pistons C.

Position of Pistons C to D.

Dead-centre position E.

Position of Pistons D beginning and F end of scavenging.

An addition to the two-stroke cycle engines of an entirely new type has been recently made. It was built by Prof. Junkers on the lines of the old Oechelhäuser gas-engine, with two pistons working in opposite directions in one cylinder but acting on the Diesel principle. This two-stroke cycle process is explained in the diagram, Fig. 19 (page 199). A horizontal 1,000-h.p. engine of this kind is at present being tested at the laboratory of Prof. Junkers at Aix-la-Chapelle. The merits of this type of engine are left for discussion.

MARINE ENGINES.

The first marine Diesel engine of 20 h.p., Fig. 20, Plate 7, was constructed in 1902–3 in France, for use on a canal-boat, by the French engineers, Adrien Bochet and Frédéric Dyckhoff, in conjunction with the author. This engine had, like the Junkers engines already mentioned, two pistons working in opposite directions in one cylinder, but the fly-wheel shaft was not at one end of the cylinder as in Junkers' engine, but traversed a cooled chamber passing straight through the combustion chamber. The engine worked on a four-stroke cycle. The great feature of this arrangement was the very high speed which was made possible by the perfect balance. This small engine worked quite satisfactorily. Others were also built in various sizes up to several hundreds of horse-power for some French submarines by Sautter, Harlé and Co., Paris.

This type of engine is of no further practical interest to-day; but while its first application to a canal-boat is of no importance in itself, it has at least the historical interest of being the first Diesel engine to be used on a boat. Since the date named the evolution of the Diesel marine engine has steadily continued, chiefly on the demand of the French submarines and Russian river-boats. The author has already mentioned that later on the high-speed four-stroke cycle engines, built for electric power stations, were made even lighter than before, and used for French submarines and for Russian river vessels. These engines were not originally reversible; on the contrary they were used to generate electricity by means of which the propellers were driven indirectly for manœuvring. In the most favourable case (Delproposto) the propulsion of the vessel was performed directly by the engine, whilst the manœuvring and slow driving were done by means of electricity. Thus Fig. 13, Plate 6, represents an engine which has been worked originally, not only as a stationary, but also as a marine engine, although it was not really designed for marine purposes.

The first reversing marine two-stroke cycle Diesel engine was built in 1905 by Messrs. Sulzer Bros. at Winterthur; it was exhibited in 1906 at Milan and fitted to a vessel on Lake Geneva in the same year. At that time engineers were not quite clear as to the importance and value of the two-stroke cycle principle, and many firms went on trying for years to make the four-stroke cycle engine reversible. The first engine of this kind was built by Messrs. Nobel Bros. at St. Petersburg in the year 1908, and was fitted to a Russian submarine. Fig 21, Plate 8, shows this 120-h.p. three-cylinder engine. It is even visible from the outside view what great mechanical complications were at first caused by the reversing of the four-stroke cycle engine. This problem has recently been solved in a much more simple and neater way, in a six-cylinder 150-h.p. reversible four-stroke cycle engine of 350 revolutions, constructed in the year 1911 by the French firm, Messrs. Delaunay-Belleville. This engine is fitted with two air-pumps, of which a spare one is for manœuvring.

In many factories reversible four-stroke cycle marine engines are still built, but, on the whole, engineers are, for navigation purposes, inclined to abandon the four-stroke cycle engine entirely and to replace it by the two-stroke cycle engine.

The small four-cylinder engine of 30 h.p. and 600 revolutions per minute, illustrated in Fig. 22, Plate 8, is also a reversible four-stroke cycle engine. It was built for experimental purposes in the year 1909, after designs by the author, as an automobile engine for heavy loads, but it can also easily work as a marine engine. The cam-shaft is mounted on the cylinder-cover, and the illustration shows the engine with the cover lifted.

The illustration above referred to is again of historical value in so far as it illustrates the first attempts to construct the Diesel engine as an automobile engine for traction wagons, and no doubt in future years these experiments, carried out in some different way, will lead to satisfactory results.

Fig. 23, Plate 8, shows a quite new Sulzer six-cylinder marine engine working at 300 revolutions, in which an innovation may be noted. The scavenging valves are not fitted on the top within the cover but below in the scavenging air-reservoir. Quite recently very large cylinder-units, single- and double-acting vertical two-stroke cycle Diesel engines, have been built. Fig. 24, Plate 8, shows one of these single-acting two-stroke cycle engines with one cylinder of 1,200 h.p., made by Messrs. Carels Frères, the results of the tests of which are as yet little known to the public. It is generally known, however, that in the Nürnberg works of the M.A.N. important experiments with large double-acting two-stroke cycle engines are being carried out.

In these works prolonged official tests of a three-cylinder double-acting two-cycle engine of 850 h.p. were made in August 1911, and the results proved highly satisfactory. At the present time a double-acting two-cycle three-cylinder engine of 2,000 h.p. per cylinder is being tested at Nürnberg. The dimensions of these cylinders are as follows:—

Diameter	800 mm. (31½ inches).
Stroke	1,060 mm. (41¾ inches).
Revolutions per minute . . .	160.

The air-supply pump for fuel injection is driven by a special Diesel engine, whilst the scavenging pumps are driven direct from the crankshaft.

If, as seems probable, these tests also give satisfactory results, the era of very large Diesel engines has begun, especially low-speed marine engines suitable for driving propellers. This last engine has already yielded considerably more than 2,500 h.p. per cylinder, so that an engine unit of this kind with six cylinders would give 15,000 h.p. or 45,000 h.p. for a vessel with three propellers. This kind of marine engine requires six cylinders to ensure a regular turning moment and balancing, so that the number of cylinders cannot be considered abnormally high; on the contrary, it must be accepted as the most suitable and proper number. The opinion which was still prevalent some months ago, that about 1,000 h.p. per cylinder is the maximum for Diesel engines, has therefore been quickly overthrown by these facts, and it may be safely assumed that the day of the large marine engine is already very near at hand. At Messrs. Krupps' Germania Works cylinder units of 2,000 h.p. double-acting two-cycle are being tested at present; also at Sulzer's Works a single-acting two-cycle cylinder of 2,000 h.p., and at Messrs. Vickers' Works a 3-cylinder single-acting, two-cycle, of 2,000 h.p. per cylinder, are being constructed.

Junkers' system, illustrated in Fig. 19 (page 199), is used for vertical marine engines. The author regrets that he has not a photograph of a finished engine.

From motives of prudence, the various navies which are now fitting some large warships with Diesel engines started with one Diesel only out of the two or three engines on board; the Diesel works alone when the ship is running at normal speed, but for high speed, steam is used as an auxiliary. It is evident that larger warships will not be fitted solely with Diesel engines until practical tests on the high seas have proved to be completely successful.

Conclusions.—As will be seen from this historical summary, countless different types of Diesel engines have been so developed that it has become very difficult for even the expert to choose between them. If one looks through the technical Press, numerous other schemes will be found on which the author will not dwell, as they have never been actually carried out. To-day, if a new firm is about to manufacture Diesel engines, it is almost impossible to give them sound advice as to the type and size they should choose from this bewildering variety. The fads, habits and tastes of the purchasers, and the kinds of machine-tools in use in the works, have to be taken into consideration rather than technical points of the engine itself. Development is proceeding so rapidly at present that, within a few months, opinions even on important points may easily be changed.

Still, the author believes that this period of chaotic production will soon be over. At present it is generally agreed that the four-stroke cycle engine from 5 up to 600 h.p. may be regarded as the exclusive type for stationary plants; but it will probably not remain so much longer in spite of its perfection, in view of the development of the two-stroke cycle engine, especially that of the double-acting type.

The use of the two-stroke cycle engine for stationary work has increased, but it is anticipated that this will be still further extended. Although this engine may never equal the four-stroke cycle engine as regards thermal efficiency, its initial cost is so much lower that its slightly higher fuel consumption will be more than counterbalanced by the greater interest and amortization on the higher-priced four-stroke cycle engine. When this stage is reached, the question is simply one of economy. In the author's opinion the two-stroke cycle engine will thus soon make headway for stationary plants. It will therefore be necessary to produce from the various systems of two-stroke cycle engines a simple standard type, with which the more complicated types will not be able to compete. It is the author's belief that this simple standard type will make its appearance very soon, and that thus the Diesel engine movement will leave the unsettled stage and enter on a period of quiet expansion.

In Appendix IV (page 216) is given a list of vessels propelled by Diesel engines, which is as complete as the author has been able to make it from private information and from publications. As many firms do not publish the details of their work, and as very little information can be obtained about anything connected with warships, such a list cannot claim to be complete. It gives only a general idea of the immense amount of work which is being done at present in this direction.

In Appendix V (page 219) some brief results of vessels propelled by Diesel engines are given, as far as it has been possible to obtain them.

SPECIAL IMPORTANCE OF THE DIESEL ENGINE FOR GREAT BRITAIN.

After this short summary about the importance of the Diesel engine for the world's industry in general and the historical review of Diesel types, the author desires to add a few words on the importance of the Diesel engine, especially for Great Britain. In this connection the three following facts must be borne in mind:—

(1) Great Britain is an exclusively Coal-producing Country;
(2) Great Britain has the largest Colonial Empire in the world; and
(3) Great Britain is the greatest Shipping Nation in the world.

Dealing with (1), Great Britain has had, at least until to-day, no natural liquid fuels of its own; it is an exclusively coal-producing country. Based on these statements, it has often been seriously put forward in recent times that England has no interest in the Diesel engine, and that it is against her most vital interest to participate in the development of this engine, as she would neglect her wealth in coal, and make herself dependent on foreign markets when using liquid fuels. The Exhibition at Turin has shown clearly that England has still very little interest in the Diesel engine as far as stationary plants are concerned owing to her abundance of coal; for in the English Section, with the exception of some very small oil-engines, only generator-gas engines were exhibited; but these were numerous, of first-class workmanship, and were built by the best firms in the country. England has therefore made great progress in power generating with gas, whilst she has up to the present given relatively little attention to power generating with liquid fuels.

But the foregoing arguments in favour of coal are not correct; the contrary is true. Great Britain has the greatest interest in replacing the coal-wasting steam-engine by the more economical Diesel engine, and this, firstly, because she can therewith effect enormous savings in her most valuable treasure—coal, and thus defer the exhaustion of her stock; and, secondly, because she can run her coal industry and the independent chemical industries on more economical lines, when using the coal in the more rational and refined way, as already mentioned. Finally, because she will also make herself free and independent of foreign markets for the supply of liquid fuels by using coal in *this way*, that is, by working the tars and tar-oils in the Diesel engine. It is not intended to imply that the whole demand of fuel for England could be produced in this way in the country itself, but through the inland production, increase of prices for foreign oils and the establishment of trusts and monopoly companies will be prevented. In this sense independence is meant.*

(2) *Great Britain has the largest Colonial Empire in the world.*—It is not possible to foresee to-day what England can obtain for her Colonies from the Diesel engine; even when using only the natural mineral oils, the Diesel engine is the predestined colonial engine, because only about the fourth or sixth part of weight in fuel has to be transported for it to the Colonies and their hinterlands, as compared with the steam-engine. For a colonial engine the cost of freightage for fuel is generally the determining factor. Further, the transport of these liquid fuels is considerably easier and more convenient than the transport of coal, especially when tank-vessels and pipe-lines are used; and finally the difficulty of working a boiler plant will only occasionally come into consideration in the Colonies, especially in the interior, except, of course, for small plants using wood, straw, and the like.

It may be mentioned, in this connection, that a pipe-line of 400 km. (about 250 miles) in length for crude petroleum is being built on the River Congo from Matadi to Leopoldville, by means of which this extensive district will be supplied, in the simplest and cheapest way, with a constant flowing fuel source, from which navigation and the railways, agriculture as well as other industries, will get their element of life, namely, motor power. This magnificent example ought to be followed in the English Colonies; it is not necessary to specify in detail the great importance of such an undertaking for them.

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* In this connection it may be of some interest to state that the tar production of Germany is sufficient for more than 5 milliards of horse-power-hours per year, which means about 1¾ millions of horse-power running 300 days of ten hours each all the year. In case of war and cutting off the supply of foreign fuel, this quantity would be entirely sufficient for running the whole fleet, war and mercantile, and for providing in the meantime the power for the inland industry as far as necessary. The author has not the figures for England, but he presumes they are of similar significance.

If one also considers that the Diesel engine can utilize vegetable oils, entirely new prospects are brought to light for the cultivation and expansion of industry in the Colonies, which are for no other country of such eminent importance as for Great Britain; and this is where she ought to start as soon as possible. The Diesel engine can be worked with the Colonies' own resources, and thus again can influence to a great extent the further expansion of agriculture in districts where it is predominant. This sounds to-day somewhat like a dream, but the author ventures to prophesy, with full conviction, that this way of using the Diesel engine will one day be of the utmost importance.

(3) Finally, *Great Britain is the greatest Shipping Nation in the world.*—When the first successes of the Diesel engine, as a marine engine, were heard of in England recently, and it was published that already numerous small mercantile and war vessels were fitted with Diesel engines, and the possibility of more important plants was mentioned, and when it was realized that larger ocean vessels were destined to be fitted with Diesel engines, and that even a warship with a very large Diesel engine was in construction, it provoked a great movement and excitement in Great Britain which is still fresh in our minds. Moreover, the reports about successful voyages with Diesel vessels under very difficult weather conditions are already increasing in number. The captains who have had Diesel engines on their vessels report on the great security and comfort in working; shipbuilders publish the figures of their savings. It is unquestionable that one of the greatest evolutions of modern industry will be connected with this

development of the Diesel engine, and that Great Britain as the greatest shipping nation of the world will derive the greatest advantage from it.

The Paper is illustrated by Plates 4 to 8 and 9 Figs. in the letterpress.

APPENDIX I.

SUITABLE OILS.

The Swiss Fuel-testing Laboratory at the University of Zürich, under the direction of Professor Constam, decided to undertake the examination of the qualities and composition of all liquid fuels which can be used for Diesel engines. These researches included the investigation of the following points:—

- (1) On the physical properties, such as
  - (*a*) Properties when cold,
  - (*b*) Properties on heating (boiling-analysis).
- (2) Chemical properties, such as
  - (*a*) Chemical constituents,
  - (*b*) Percentage of H_2O and Ash,
  - (*c*) Calorific power.

This Laboratory is destined to become a centre for the investigation of fuels for Diesel engines on account of the perfection of its equipment, the accuracy of its work, and the excellence of its management. The Laboratory intends to publish from time to time exhaustive reports of its researches.

From tests and examinations already made, power oils have been divided into the following three classes:—

1. *Normal oils which can always be used:*

(*a*) Mineral oils freed from benzene (gas oils) . . .	Hydrogen over 10 per cent. Calorific power over 10,000 cal. per kg. (18,000 B.Th.U. per lb.). No solid impurities.

(*b*) Lignite tar oils .	Hydrogen over 10 per cent. Calorific power over 9,700 cal. per kg. (17,460 B.Th.U. per lb.).
(*c*) Fat oils from vegetable or animal sources, such as earthnut oil, castor oil, fish oils, etc.* .	Scarcely any researches have been made on these. Earthnut oil has 11·8 per cent. hydrogen, and calorific power 8,600 cal. per kg. (15,480 B.Th.U. per lb.).

2. *Oils which can be used only with the aid of special apparatus :—*

(*a*) Pit coal-tar oil.

(*b*) Vertical-oven, water-gas and oil-gas tars, probably also coke-oven tars, the tests on which have not yet been completed.

General characteristics :

Hydrogen not over 3 per cent. ;
Amount of free carbon not over 3 per cent. ;
Residue on coking not over 3 per cent. ;
Calorific power not under 8,600 cal. per kg. (15,480 B.Th.U. per lb.).

3. *Oils which cannot be used :*

Tars from horizontal or inclined retorts.

It must not be understood that these will not be used in Diesel engines under special conditions ; but, on the whole, the above classification is accurate in the present state of development of the Diesel engine.

It is evident that for estimating the value of power oils, not only the above qualities, but all their chemical and physical properties must be considered, which is only possible after a thorough investigation of each kind of oil.

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* This class of oil has been added by the author from his own investigations of earthnut oil.

APPENDIX II.

SPECIFICATIONS OF TAR-OIL SUITABLE FOR DIESEL ENGINES.

(*From the German Tar Production Trust at Essen-Ruhr.*)

(1) Tar-oils should not contain more than a trace of constituents insoluble in xylol. The test on this is performed as follows:—25 grammes (0·88 oz. av.) of oil are mixed with 25 cm^3 (1·525 cub. in.) of xylol, shaken and filtered. The filter-paper before being used is dried and weighed, and after filtration has taken place it is thoroughly washed with hot xylol. After re-drying, the weight should not be increased by more than 0·1 gr.

(2) The water contents should not exceed 1 per cent. The testing of the water contents is made by the well-known xylol method.

(3) The residue of the coke should not exceed 3 per cent.

(4) When performing the boiling analysis, at least 60 per cent. by volume of the oil should be distilled on heating up to 300° C. (572° F.). The boiling and analysis should be carried out according to the rules laid down by the Trust.

(5) The minimum calorific power must not be less than 8,800 cal. per kg. For oils of less calorific power the purchaser has the right of deducting 2 per cent. of the net price of the delivered oil, for each 100 cal. below this minimum.

(6) The flash-point, as determined in an open crucible by Von Holde's method for lubricating oils, must not be below 65° C. (149° F.).

(7) The oil must be quite fluid at 15° C. (59° F.). The purchaser has not the right to reject oils on the ground that emulsions appear after five minutes' stirring when the oil is cooled to 8° (46° F.).

Purchasers should be urged to fit their oil-storing tanks and oil-pipes with warming arrangements to redissolve emulsions caused by the temperature falling below 15° C.

(8) If emulsions have been caused by the cooling of the oils in the tank during transport, the purchaser must redissolve them by means of this apparatus.

Insoluble residues may be deducted from the weight of oil supplied.

APPENDIX III (*continued on opposite page*).

PROPERTIES OF PIT-COAL TARS.

(*By* W. ALLNER. *On the Application of Tar for the Working of Diesel Engines.*)

—	Specific Gravity.	Water.	Free Carbon.	Flash-point.	Burning-point.
VERTICAL-OVEN TAR (Gasworks of the D.C.G.G.):—					
English coal	1·124	5·0	3·65	44	100
Do. do.	—	3·0	1·87	71	—
Do. do.	—	2·1	1·25	45	104
Westphalian coal . . .	—	2·0	1·17	42	99
Upper Silesian coal . . .	—	1·0	0·23	40	75
Westphalian coal . . .	1·123	1·0	1·66	—	—
Do. do. . . .	1·182	1·5	1·60	—	—
Westphalian and English coal .	1·091	1·7	4·26	—	—
Do. Do. do.	1·092	2·9	1·13	—	—
Silesian coal	1·097	1·0	1·86	—	—
HORIZONTAL-OVEN TAR (Gasworks of the D.C.G.G.):—					
English coal	—	4·0	21·7	71	125
Do. do.	1·246	8·0	28·8	90	130
English and a little Silesian coal	1·231	5·5	32·99	—	—
Do. do. Do. do.	1·160	6·6	14·85	—	—
Silesian coal	1·210	4·9	23·76	—	—
Westphalian coal . . .	1·228	3·6	26·79	—	—

APPENDIX III (*continued on next page*).

Properties of Pit-Coal Tars.

(*By* W. Allner. *On the Application of Tar for the Working of Diesel Engines.*)

Viscosity at °C.						Thermal units (Higher Calorific Power) per 1 kg. (Undried Tar.)	Analysis of Dry Tar.			Percentage.
20	50	70	75	80	100		C	H	S	
39·3	3·9	2·2	—	1·7	—	—	—	—	—	—
75·5	4·5	2·2	—	—	—	8986	—	—	—	—
7·8	2·5	1·5	—	—	—	9185	—	—	—	—
10·1	2·1	1·4	—	—	—	8890	—	—	—	—
6·9	1·8	1·3	—	—	—	9132	—	—	—	—
—	—	—	—	—	—	9103	—	—	1·42	—
—	—	—	—	—	—	9015	—	—	0·50	—
—	—	—	—	—	—	9163	—	—	0·33	—
—	—	—	—	—	—	9129	—	—	0·52	—
—	—	—	—	—	—	9378	—	—	0·48	—
114·4	16·0	7·2	—	—	—	8766	—	—	—	—
550·0	51·0	23·0	—	18·9	—	—	—	—	—	—
—	—	—	—	—	—	8615	—	—	1·25	—
—	—	—	—	—	—	8576	—	—	0·46	—
—	—	—	—	—	—	8709	—	—	0·35	—
—	—	—	—	—	—	8729	—	—	0·46	—

APPENDIX III (*continued on opposite page*).

PROPERTIES OF PIT-COAL TARS.

(*By* W. ALLNER. *On the Application of Tar for the Working of Diesel Engines.*)

—	Specific Gravity.	Water.	Free Carbon.	Flash-point.	Burning-point.
VERTICAL-OVEN TAR (Cologne Gasworks):—					
Westphalian coal	1·12	—	1·5 ÷ 2·5	—	—
HORIZONTAL-OVEN TAR (Cologne Gasworks):—					
Westphalian coal	1·20	—	20 ÷ 25	—	—
VERTICAL-OVEN TAR (Zürich Gasworks):—					
Ruhr coal ($\frac{1}{3}$ less water than coke-oven tar when stored for an equal period)	—	—	ca. 5	—	—
COKE-OVEN TAR (Zürich Gasworks—older ovens):—					
Ruhr coal	—	—	15 ÷ 25	—	—
HORIZONTAL-OVEN TAR (Various kinds of coal):—					
Saar coal	—	7·9	31·7	—	—
Ruhr coal	—	9·3	35·2	—	—
Silesian coal	—	11·0	29·2	—	—
English coal	—	9·6	36·9	—	—
For Comparison :—					
Paraffin oil	0·893	—	—	81	113
Tar oil	1·008	—	—	63	97

APPENDIX III (*concluded from page* 212).

Properties of Pit-Coal Tars.

(*By* W. Allner. *On the Application of Tar for the Working of Diesel Engines.*)

Viscosity at °C.						Thermal units (Higher Calorific Power) per 1 kg. (Undried Tar.)	Analysis of Dry Tar.			Percentage.
20	50	70	75	80	100		C	H	S	
—	—	—	—	—	—	—	—	—	—	Pitch 25–30
—	—	—	—	—	—	—	—	—	—	55–60
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	138	—	24·6	—	8·3	8910	92·48	4·44	0·25	—
—	—	—	43·1	—	—	8855	92·48	4·29	0·17	—
—	—	—	19·4	—	—	8835	92·37	4·59	0·25	—
—	—	—	—	—	132	8826	92·8	4·21	0·42	—
1·36	1·11	1·02	—	—	—	10511	—	—	—	—
1·38	1·15	1·04	—	—	—	9470	—	—	—	—

APPENDIX IV.

LIST OF VESSELS PROPELLED BY DIESEL ENGINES.

(Built or in course of construction up to November 1911; and compiled from publications and private sources.)

As a good many firms maintain strict secrecy about their work in this direction, and as the information obtainable about naval ships is both scarce and unreliable, the lists are not complete. In any case the figures are minima.

(a) *Oil-Tank Vessels* (21).—Of these there are:—

12 Russian: On the Volga and the Caspian Sea, principally transporting oil for Messrs. Nobel Brothers, St. Petersburg. The largest of these vessels is the "Djelo," 5,000 tons displacement, 1,000–1,200 h.p.

4 German: For the German-American Oil Co. (Standard Oil Co.). Largest vessel, 15,000 tons displacement, 3,500–4,200 h.p. In construction at Messrs. Krupps' Germania Works. The vessel will be constructed on the Isherwood system, and is to contain 22 tanks.

3 Dutch: For different oil companies, one of which is the Anglo-Saxon Petrol Co., London. The largest vessel is 9,300 tons displacement and 2,200 h.p.

1 English: For Messrs. Furness, Withy and Co., Hartlepool. The ship, 3,150-ton cargo boat, is being built by Sir Raylton Dixon and Co., of Middlesbrough, and the engines—800 b.h.p. "Carels-Westgarth," two-stroke engines with four cranks—are by Messrs. Richardsons, Westgarth and Co., of Middlesbrough.

1 American: For Canadian Lakes, for Standard Oil Co., New York.

It is known that Messrs. Nobel of St. Petersburg are gradually converting their whole fleet on the Volga and Caspian Sea, consisting of 50–60 ships of different sizes, into Diesel-engined vessels. It is not known how many of them have already been thus converted.

(b) *Tugs* (37).—Of these most (about 22) are Russian, for use on the Caspian Sea and the Russian tributaries.

2 of them have a towing capacity of 13,000 kg. (12·8 tons) with 800 h.p.
3 of them have a towing capacity of 8,200 kg. (8 tons) with 600 h.p.
The power of the others averages about 400 h.p.

3 German: On the River Elbe (150 h.p.); on the River Weser (200 h.p.); on the River Rhine (400 h.p.).

The remainder are for various countries, namely, Chile, Italy, Sweden, Roumania, etc.

(c) *Motor Sailing-Vessels* (8).—Of these 2 French boats are the most noteworthy:—

French: (1) The four-master "Quevilly," with about 6,500 tons displacement and 600–700 h.p. (2) The five-master "La France," the largest sailing-vessel in the world, with about 11,000 tons displacement and 1,800–2,000 h.p.

1 German, 1 English, 1 Dutch, 1 Swedish, and 1 Italian motor sailing-vessels.

(d) *Merchant Vessels* (*about* 43) (*Freight, Passenger, and combined Freight and Passenger Vessels*).—Of these:—

9 are Russian, including: 6 passenger vessels on the Volga, about 2,000 tons displacement and 1,200 h.p.

7 German, including: 1 vessel, built by Blohm and Voss for the Hamburg-America Line, of 9,000 tons displacement and 3,000 h.p. 1 vessel for Hamburg-South America Steamship Co. of 6,000 tons displacement and 850 h.p.

7 Scandinavian, including: 3 vessels for the Danish-East Asiatic Co. of 2,500–3,000 h.p.

4 Dutch, 3 English, 2 Swiss, 2 Congo Free State, and the others various, including: 1 freight and passenger vessel, "Romagna," on the Adriatic Sea for the Ravenna-Trieste-Fiume service, of 1,000 tons displacement and 800 h.p. This vessel unfortunately sank a few months ago owing to faulty loading of its cargo.

Most of these vessels, especially the larger ones, will not be put in service until 1912. Of the Russian passenger vessels a good many are already in operation.

(e) *Fishing Boats* (14).—Of these:—

11 are German herring-boats of 254 tons displacement and 90 h.p. for the North Sea.

2 English whalers for the South Polar Sea with 200 h.p.; etc.

(f) *Miscellaneous* (*about* 16).—Of these:—

3 are Russian, including: 1 private yacht, 200 h.p., and 2 for the Russian Minister of the Interior.

3 French: Private yachts, including 1 of about 400 tons displacement and 400–500 h.p.

2 German: The lightship "Hamburg" and the test-ship "Bremen."

1 Norwegian: "Fram," exploring vessel for the South Pole, Captain Amundsen, 380 tons capacity and 180 h.p.

(g) *Submarines* (*about* 110–115), including, as far as can be ascertained, up to the end of 1910:—

About 60–70 French, of 390–800 tons displacement and 600–5,000 h.p.; about 13 Russian, 13 English, 2 Dutch, 2 Danish, 1 Norwegian, 1 Swedish, 1 American of 1,200 h.p., 2 Italian, 2 Austrian.

It is probable that the number of vessels has been considerably increased in 1911, and that a large number will be added in the future. Various countries are not mentioned in the list, for instance, Germany, Japan, the South American States, etc. It is almost impossible to publish a list which is absolutely accurate, owing to the secrecy about the number of vessels in construction and the kinds of engines used on them.

(h) *Warships* (*about* 20–30):—

Here again it is impossible to give accurate figures, as the information published is very scarce and contradictory. It is, however, known that several Navies are experimenting with Diesel engines on a large scale. The following are especially noteworthy: A great number of gun-boats and a few mine-laying boats for the Russian Navy. Also 1 French, 1 English torpedo-boat destroyer, and 1 Italian.

(i) *Small Boats* (*about* 15–20):—

In the list of Navy vessels, although they are not strictly men-of-war, must be included the small boats such as pinnaces, and special boats, of which about 15–20 are destined for the German, Swedish, English, Argentine, and Russian Navies.

Summary.

(*a*) Oil-Tank Vessels	about	21
(*b*) Tugs	,,	37
(*c*) Motor Sailing-Vessels	,,	8
(*d*) Merchant Vessels, Freight, Passenger and Combined Vessels	,,	43
(*e*) Fishing Boats	,,	14
(*f*) Miscellaneous	,,	16
(*g*) Submarines	,,	115
(*h*) Warships	,,	30
(*i*) Small Boats	,,	20
Total		304

APPENDIX V.

Brief Results from some Vessels propelled by Diesel engines (see Appendix IV).

(*a*) OIL-TANK VESSELS.

Russian Oil-Tank Vessel "Vandal":—

Put in commission 1904. 1,150 tons displacement, 360–450 h.p. The first oil-tank vessel built for the Volga and Caspian Sea. Reversing (electric) from full speed ahead to full speed astern in 8–10 seconds. Cost for repairs, lubricating, and cleaning for the working year 1906, M.7,440 (£364). Sailing radius, unloaded 13,000 sea miles; loaded 12,000 sea miles. Mileage in 1905—21,300 km. (11,472 sea miles); 1906—22,400 km. (12,073 sea miles).

Russian Oil-Tank Vessel "Sarmat":—

Put in commission May 1905. 1,150 tons displacement, 360–430 h.p. Volga and Caspian Sea. Reversing (Delproposto). Sailing radius at full speed 14,000 sea miles unloaded; 12,900 sea miles loaded. Mileage 1906, 19,200 km. (10,348 sea miles).

Russian Oil-Tank Vessel "Djelo":—

5,300–5,700 tons displacement, 1,000–1,200 h.p. Made several stormy voyages on the Caspian Sea in the year 1911.

Dutch Oil-Tank Vessel "Vulcanus":—

Put in commission in the summer of 1911. 2,500 tons displacement, 500 h.p. Fuel consumption for 100 English sea miles, 1,000–1,100 kg. (2,204–2,425 lb.). Daily crude-oil consumption 2½ tons for full load. Saving in cost of fuel as against steam-engine, 50 per cent. Voyage Rotterdam–Stockholm in July 1911: 735 sea miles in 100 hours with cargo of 1,000 tons of oil and at a speed of 8·5–8·9 knots. Fuel consumption 8½ tons. The "Vulcanus" has already made a very successful voyage of 32 days' duration to the Black Sea and back, and numerous voyages from Holland to Sweden and England.

(*b*) TUGS.

Russian Tug "Jakut":—

Towing capacity 4,000 tons, 320 h.p. The engines have already worked satisfactorily for two years. The manœuvring power is better than with steam-engines. The "Jakut" and a steam ice-breaker went to the assistance of a ship and towed her out of the ice. On this occasion the fuel consumption of the "Jakut" was 4,380 kg. (9,654 lb. or 4·3 tons) as compared with 32,500 kg. (71,630 lb. or 32 tons) by the steamer.

German Tug "Fortschritt" in Hamburg Harbour:—

150 h.p. Has also made very stormy voyages on the open sea and carried fuel for 8 days. Gain in length one-third over a steamer. Gain in weight of machinery about one-fourth over steam plant. Weight of fuel only 20–25 per cent. of weight of coal for the same power in a steamer.

"*Frerichs*":—

Towing capacity 2,200 tons, 200 h.p. Manœuvring power same as in a steam vessel. The vessel pays the same insurance premium as a steam vessel. Owing to the absence of boiler and coal bunkers, there is space for the accommodation of 20 passengers. Owing to the absence of the boiler plant the stern of the vessel was made smaller, so that the vessel was more easily handled and the turning circle was diminished. 30 manœuvres can be carried out in one hour without a change in the air pressure in the starting-tanks. With the quantity of air stored in the starting-tanks 60 manœuvres can be carried out in succession. A starting-tank holds 250 litres (55 gal.), and when completely emptied the pumps can fill it in 15 minutes.

(*c*) MOTOR SAILING-BOATS.

"*Quevilly*":—

About 6,500 tons displacement, 600–700 h.p. on two propellers. The propellers can be uncoupled when using sails only, and their resistance when running light causes a loss of speed of ½ knot. The first ship to cross the Atlantic.

1st voyage: Rouen–New York and back in March 1911. Engines working during 1,200 hours.

2nd voyage: Rouen–New York and back in July and August 1911. Cost of fuel 1 dollar per hour per engine. Very satisfactory results.

3rd voyage: Havre–New York, lasted 38 days, during 26 days (about 650 hours) of which the engines worked against a strong wind.

The vessel can enter harbours without the help of tugs. The vessel takes up its fuel in New York for the double journey at a price of 32 M. (31*s.* 4*d.*) per ton, or 6 Pf. (0·7 penny) per e.h.p. hour.

"*La France*":—

Largest sailing-vessel in the world. 10,730 tons displacement, 1,800–2,000 h.p. Sail area 6,500 m^2 (69,966 sq. ft.). Will run between France and New Caledonia, and was launched on the 16th November 1911.

"*Orion*":—

60 h.p. Has made voyages since November 1907 to and from Sweden, Finland, Russia, Germany, and Denmark. The engine is very often used in combination with the sails, and is only in charge of a single carpenter.

(*d*) MERCHANT VESSELS.

(*Freight, Passenger, and Combined Freight and Passenger Vessels.*)

"*Rapp*" *and* "*Snapp*":—

2 small merchant vessels cruising in the Swedish waters. Cargo capacity 300 tons, 120 h.p. The engines run for long periods at 55–60 revolutions, although the normal number of revolutions is 300. Since 1908 the vessels have made numerous voyages between Sweden, Finland, Germany, Holland, England, Iceland and Norway. On a voyage from the east to the west coast of Sweden, through the canals, 75 locks had to be passed, through which the manœuvring power proved to be very satisfactory.

"*Cornelis*":—

200 h.p. Has already made numerous voyages between Antwerp and London and Aberdeen. Fuel capacity is sufficient for 32 days.

"*Uto*":—

Passenger vessel on Lake Zürich. 200 tons displacement, 250–260 h.p. Has made regular passenger trips on Lake Zürich since the summer of 1909. Converted steamer. Weight of the previous steam plant, including coal and water, 14,700 kg. (14·46 tons) for 120 km. (64·6 sea miles) radius. Weight of the new plant, for the double power and 1,200 km. (646 sea miles) radius, is 9,750 kg. (9·6 tons). Cost of fuel one-fourth of the previous cost. Saving in labour, 1 man. Cost of fuel per km. 10·5 cts. (1·6*d.* per mile).

"*Toiler*":—

First Diesel sea-going vessel. Cargo capacity about 3,000 tons. 360 h.p. The steering is controlled by compressed air. The cabins are warmed by hot water heated by the exhaust from the engines. First voyage from the Tyne to Calais with a cargo of coal was made in the summer of 1911 in very bad weather. Oil consumption 1·65–1·75 tons in 24 hours. A steamer of the same size consumes 8–9 tons of coal per day. Saving in cost of fuel as compared with steamer 50 per cent. Gain in cargo capacity 60 tons. Voyage to North America in September 1911. Fuel consumption 2 tons per day. Saving in cost of fuel as compared with steam plant $11 (45*s.*). Saving in labour $5 (20*s.* 10*d.*) per day. Manœuvring power proved to be very satisfactory.

"*Romagna*":—

1,000 tons displacement, 800 h.p. Put in commission September 1910. Made regular voyages between Ravenna-Trieste-Fiume in the summer of 1911. In consequence of the faulty loading of the cargo the vessel sank in a terrible sirocco in November 1911.

Vessel of the Hamburg-America Line:—

9,000 tons displacement, 3,000 h.p. Gain in weight and space as compared with a steam plant of the same size, 40–50 per cent.

(*e*) FISHING BOATS.

"*Ewersand*":—

German herring-boat, built by Frerichs in Bremen. 254 tons displacement, 90 h.p. Gain in cargo capacity as compared with steam fishing boat 25 per cent. Can take up 750 casks of herrings instead of 600. First voyage in September 1910 lasted five weeks. Consumption of crude oil, 3 tons as against 20 tons of coal for steamer. Homeward journey in 75 hours without a stop, in a high sea. On its arrival at the end of October 1910, 3 tons of crude oil were still unconsumed. Very favourable results, and consequently an order for ten more similar fishing boats was placed.

(*f*) MISCELLANEOUS BOATS.

"*Fram*" (South Polar Ship):—

It is the old North Polar ship "Fram" fitted with Diesel engine. Gain through replacing the steam-engine by Diesel engine: In engine space 45 per cent.; weight of engine 60 per cent.; weight of fuel 80 per cent.; space for fuel 85 per cent. Several years' supply of fuel can be stored. Of 380 tons cargo capacity 100 tons were previously required for the coal storage. The "Fram" sailed for six months from Christiania to the South Polar regions without touching land and without reporting. During the voyage in the

Antarctic the engine worked for 2,800 hours without giving any trouble.

(*g*) Submarines.

French Submarine "Aigrette":—

172–220 tons displacement, 217 h.p. Long voyage from Cherbourg to Dunkirk and back in October 1908.

"Emeraude":—

390–450 tons displacement, 600 h.p. In October 1908 she made an uninterrupted voyage of 80½ hours on the high seas (1,283 km. or 692 sea miles). The average speed was 9 knots, and the engine worked excellently during the whole voyage. At the beginning of 1909 a long voyage of 800 sea miles was made on the high seas.

"Opale":—

390–450 tons displacement, 600 h.p. In September 1907 made a voyage of 550 sea miles at a speed of 8–9 metres (26–29·5 ft.) per second in difficult navigating conditions. At the beginning of 1909 made a long voyage of 800 sea miles on the high seas. Sailed from Cherbourg to Lorient in 34 hours.

"Circe" and "Calypso":—

350–490 tons displacement, 300 h.p. Made a trial trip in the spring of 1910 from Toulon to Nice, Corsica, and back to Toulon, or 600 sea miles in 58 hours. The engines worked excellently.

The experience obtained with Diesel engines on submarines is so satisfactory that to-day all the navies in the world have, almost without exception, Diesel engines on their submarines. The good results obtained on this kind of vessel were the reason for the fitting of Diesel engines on all other kinds of vessels.

(*h*) Warships.

Russian Gun-Boats "Adragan" and "Kars":—

700 tons displacement, 1,000 h.p. These two vessels made very satisfactory trial trips in the summer of 1911 on the Caspian Sea. Before making these trial trips they sailed from St. Petersburg to the Caspian Sea over the Neva, Lake Ladoga, the canal-system and the Volga, arriving on the 19th May 1911. It is well known that the Caspian Sea is as stormy as the open sea, and owing to its ice, travelling is considerably more difficult and dangerous for navigation in the winter.

APPENDIX VI.

MOTOR-BOAT SHIPPING IN THE COLONIES.

(Being a summary of the technical portions of a Paper read by Dr. R. Diesel, Engineer, at a meeting of the Technical Commission of the Committee of Colonial Economy at Berlin on the 13th November 1911.)

The technical side of motor-boat shipping is divided into two parts: Boat and Motor.

The African rivers require a special type of flat-bottomed boats, because of their peculiar nature; but there is no difficulty in constructing these boats and the author has already given many examples of boats on the River Nile and River Congo, on the latter river one boat with 1,300 h.p., tonnage 450 tons, and only 1·10 metres (3·6 feet) draught. Another boat for the Congo, constructed by the English Bolinder Company, with 40–50 h.p. engine, length 14 metres (45·9 feet), width 3–4 metres (9·8–13·1 feet) and a speed of 8 knots, can carry a net load of 5 tons. It draws only 0·85–0·88 metre (2·78–2·88 feet). By placing the propellers in a sleeve, sufficient driving-power is still obtained, when the propeller is partially immersed, for draughts of 0·5 metre (1·64 feet) and less. Messrs. Cockerill at Seraing constructed a small boat with two protected propellers, for a draught of 35 cm. (1·15 feet). It is provided with winches to float it when aground. A French boat-constructor has built a boat with only 10 cm. (4 inches) draught.

The problem of the boats is therefore solved, but not the problem of the engine.

The great importance of navigation for the colonies is indisputable; the river navigation is actually carried on by steam-engines, but they were prevented from great development by the high price of coal. At Stanleyville a ton of marine coal costs 400 francs, which is about 20 to 30 times more than the cost in Europe. This high price makes the working of steam-engines with coal prohibitive. A quantity of 30,000 tons of coal per year would be necessary at Leopoldville for the steam-vessels at present on the River Congo, but the small-gauge railway, Matadi-Leopoldville, can only transport a daily quantity of 50 to 60 tons. It is quite out of the question therefore that the coal stations in the interior can also be supplied with coal. It was proposed to work the vessels with gas-engines instead of steam-engines; this would mean that only about two-thirds of the coal would be required, but even this small quantity could not be transported by the railway. In addition to that, a special quality of coal would be required, the cost of which would be still considerably higher. The only way to overcome these difficulties was to use wood as fuel. When steam navigation was first started on the Congo it was not difficult to obtain the necessary quantities of wood, but with increased traffic too much wood would be required, and the forests would be destroyed.

If one considers that the 500-ton steamer from Leopoldville to Stanleyville requires 16 tons of wood for each 10-hour voyage, and that it has to take in fresh fuel every 10 hours, it is evident that navigation cannot rely on this fuel for the future development and increase. Certainly the price for fuel when using wood was only about 15 centimes (1½*d.*) per effective h.p. as compared with 40 centimes (4*d.*) for gas coal, and 60 centimes (6*d.*) for steam coal. This price is very low, but, notwithstanding this, wood cannot be the fuel for the future, owing to the foregoing reasons, and steam and gas engines would therefore have to be excluded from working in the colonies.

The question then arises as to the suitability of internal-combustion engines. So far as the author can ascertain, there are already some small motor-boats with explosion motors used in the colonies, but this cannot be called motor navigation. The danger of the fuel and its high price makes navigation on a large scale impossible for the colonies; it will only be used occasionally on small boats and motor-cars.

The only engine to be considered therefore is the Diesel, and the author showed in his earlier Paper that it is the predestined colonial engine owing to its development during the last few years, and its adoption as a marine engine. It was further shown that it could be worked on any mineral oil. These mineral oils are in all parts of the globe, so that their prices vary very slightly in the different ports, from 40*s.* to 60*s.* per ton; for instance, the price for American mineral oils for Diesel engines in London and Great Britain is 43*s.* per ton, being equal to the price in Belgium and in Scandinavia. Russian oil is delivered to all the Italian ports at a price of 60 fr. (48*s.*) per ton, and this amount is the same in all the other ports of the Mediterranean. In Egypt numerous Diesel engines are working on these oils.

The Diesel engine consumes only about 200 grammes of this oil per effective h.p.-hour at an average cost of 0·12*d.* The consumption of fuel in the Diesel engine is so low that the same number of horse-power can be obtained with a fifteenth part of the weight of the fuel as compared with wood fuel. If, therefore, Congo steam-vessels with 15 tons of wood on board can make a voyage of 10 hours, the same vessel with 15 tons of liquid fuel can make a voyage of 150 hours, besides the saving in time which is effected by not having to call at ports for fresh supplies of fuel.

A vessel fitted with a Diesel engine can take any quantity of liquid fuel on board, which can easily be stored in the bow and stern of the ship where it does not occupy room available for cargo, and it can make long voyages into the interior, taking considerably shorter time than a vessel fitted with steam-engines and boilers for wood fuel.

Another very important point is that the costs for working would not be higher in the interior of Africa than near the coast or in Europe, presuming that no duties would be charged for these fuels; it is to be expected that the latter will not be the case, so that this new colonial industry shall have an opportunity of expansion without any restrictions.

To make it clearer, the author again states the cost of fuel per effective h.p.-hour for the different kinds of fuels mentioned above:—

Steam-engine with coal-fuel . .	about	60	centimes	(6*d.*)
Gas-engine with coal-fuel . . .	,,	40	,,	(4*d.*)
Steam-engine with wood-fuel . .	,,	15	,,	($1\frac{1}{2}$*d.*)
Diesel-engine with mineral oil-fuel .	,,	1–2	,,	($\frac{1}{10}$*d.* – $\frac{1}{5}$*d.*)

Another proposal made was to keep the steam-engine, but to heat boilers with mineral oil. Some vessels of this kind were built, but the proposition to develop them for the use of the colonies was negatived by the fact that a steam-engine of equal horse-power with a Diesel engine consumes about 4–5 times more mineral oil than the latter.

The great importance of these circumstances for developing the colonies was first recognized by King Albert of Belgium, who had made a journey to the Congo to study the question, and is now working out extensive projects for its colonization. The author had the honour of laying his proposals before the King at an audience, and the result was the order for a large Diesel engine mail-vessel for the Congo River, placed with Messrs. Cockerill at Seraing, which is the first real colonial motor-ship. The main dimensions of this vessel are as follows: length 60 metres (196·85 feet), width 8 metres (26·25 feet), draught 1·10 metres (3·6 feet), and tonnage 430 tons. The vessel will have three decks, one of which is intended for the natives and the other two for the Europeans. The motor power is 1,300 h.p. with two propellers, each exerting 650 h.p., speed 25 km. (15·5 miles) per hour. The length of journey to and from Leopoldville to Stanleyville without taking in fresh fuel is 4,300 km. (2,672 miles). This distance, to and fro, has to be covered in 140 hours, or about 14 days, whilst the paddle steamers make it in 32 days at present. Stock of fuel is 50 tons, and of this stock 15 to 20 tons have to remain at the end of the voyage so that the vessel is able to supply from its stock smaller boats in the interior which run on tributaries. The cost of this vessel—1,000,000 frs. (£40,000)—will be paid by the King himself.

It was stipulated that the natives should be able to take charge of the engines, which necessitated a very simplified trial engine being built first; this engine recently made a successful test. The engines for the Congo mail-vessel will now be built after this type.

The example shown by King Albert has had an immediate result by the formation of the Société Anonyme des Petroles du Congo with a capital of 6,000,000 frs. (£240,000). The Company bound itself to the Belgian Colonial Corporation to lay down petroleum stores along the Congo and its tributaries in which petroleum for at least three months must be kept. The pipe-line must have a diameter of at least 10 cm. (4 inches) and the pump-engines (eight stations) must be powerful enough to deliver at least 50,000 tons of petroleum to the end of the pipe-line. As a return, the Company received from the Congo Government all the land up to 1,000 hectares (2,471 acres) for all the plants, on lease without payment. The concession holds good for 50 years, and after this time all the pipe-lines with the material, except the vessels and the stores of petroleum, will pass into the possession of the Congo Government.

The Government reserve the right to buy all the pipe-lines after fifteen years, by payment of capital invested in the plant after depreciation and the reserve funds have been deducted, but with a premium of 33·33 per cent. calculated on the whole amount. The stock of petroleum has to be taken over at cost price, and the petroleum tank-vessels at a price fixed by experts.

The selling price of the petroleum is the local price at Matadi Dock, plus 15 per cent. The price at Matadi is fixed between the two parties. The selling price at the station higher up the river than Matadi is fixed in such a way that 15 centimes (1½*d.*) are added for each km.-ton to the Matadi Dock price. These prices hold good for supplies of at least 7 tons per year, and for smaller supplies an increase of 10 per cent. can be obtained. If the net profit does not come up to 7½ per cent. within two years, after having made all deductions and depreciation, the price can be increased one cent per km.-ton, and it must be decreased the same amount if the net profit is more than 7½ per cent. The petrol supply for the Congo is thus secured, and the first condition, the supply of the necessary fuel, is fulfilled.

The calculations for the pipe-line have been based on the fact that the consumption of wood fuel higher up the Congo is equivalent to 20,000 to 22,000 tons of petroleum yearly, but it is certain that at the beginning this large quantity of petroleum will not be wanted, especially during the experimental period, and because motor navigation on the Congo itself can only be taken into consideration, as the navigation on the tributaries will still use wood fuel.

The vessels at present in use, about 4,000 h.p., will also work on wood fuel until the Diesel engine vessels are supplied. The locomotives of the Matadi and Leopoldville Railway will also work on petroleum in the future, and experiments in this direction have already been made on three locomotives. It is also anticipated that the existing petroleum piping will be the reason for the erection of a good number of stationary and agricultural Diesel engines, and thus there will be new customers for petroleum.

Considering the conditions given above, the price for the mineral oil per ton would be:—

At Matadi Quay	about 75 frs.	(60/–)
Plus 15 per cent.	11 ,,	(8/10)
	86 frs.	(68/10)
400 km. higher up in the country an addition of 400 × 15–	60 ,,	(48/–)
Therefore price per ton	146 frs.	(116/10)

Numerous Diesel engines are working in many European countries where the prices for mineral oils are the same owing to the high duty which has to be paid. But navigation on the main streams would be independent of this increase in price, as the vessels could take any amount of fuel on board at the beginning of their voyage, to be sufficient for the journey to and fro.

As already stated, the large vessels on the main rivers can give to the ships in the interior their surplus fuel; thus cheap navigation can be carried on along the rivers furthest in the interior. From this it follows that, where there are rivers in the colonies, motor navigation ought to be started first, and thus the very expensive construction of railway lines will be obviated. Important districts without rivers would get small railways to connect them, and the locomotives can also be driven by Diesel engines.

The construction of the colonial Diesel engine ought to be as simple as possible, and only very few patterns of cylinders and other parts ought to be built, so that it would be possible to exchange and replace single parts easily; larger units ought to be set together by adding 2, 3, 4, and more cylinders. The engine working with many cylinders is not a drawback, but a good feature, because the engine can continue working even if one cylinder stops; another feature connected with the simplicity of construction is that only very few spare parts are required, and that the same spare parts can be used for all the cylinders. These spare parts can be stocked all over the colony, and would prove to be very useful if all the Diesel engines in one district were of the same pattern. This, however, can only be considered when the Diesel engine has become well introduced. The importance of the possibility of using vegetable oils in the Diesel has already been discussed in the Paper.

Discussion.

The Chairman (Sir H. Frederick Donaldson, K.C.B., Vice-President) thought it was quite unnecessary for him to move a vote of thanks, because the members had been a little ahead of him in their expression of pleasure for the Paper that had been just read, but none the less gladly he would ask the members to accord a very hearty vote of thanks to the author for coming over to England and giving the Institution so extremely interesting a Lecture. The subject was one which must have been exceptionally difficult for the author to handle, without touching on ground that had been covered by other investigators of his system. There were a good many speakers who were prepared to speak that evening and to elicit some further information from Dr. Diesel, and without further words he would move a very hearty vote of thanks.

The resolution was carried with acclamation.

The Chairman said the author found it impossible to come over to an adjourned Meeting of the Institution, and it was obvious that the subject should only be discussed in his presence. Consequently it became necessary to complete the discussion that evening, and subsequent remarks on the Paper could be put into writing and included in the Proceedings.

Mr. **DUGALD CLERK** (Member of Council) said he had listened with the greatest interest to the valuable Paper which told in a clear and modest manner the struggles the author had had with the Diesel type of engine from 1892 onwards. He sympathized with the author because he was himself an old internal-combustion engine inventor, having begun his work on such engines as early as the year 1876, and accordingly he had a vivid idea of the difficulties which the author had had to face. He had watched his progress from 1892, when he began with the view of applying the Carnot cycle to practice, but soon gave up that idea because he found that with the pure Carnot cycle in practice he would have about 500 lb. per square inch for compression pressure and about 6 lb. for his mean pressure. Seeing that that engine would be impracticably heavy, he proceeded on less ambitious lines. There were many difficulties to be contended against, and there was only one other inventor whom he knew who had had to meet difficulties of equal magnitude. The Hon. Sir Charles Parsons was the other inventor to whom he referred. Sir Charles Parsons began his long struggle in 1884 and now had met with the most phenomenal success. It was given to few inventors to realize their whole anticipations as Sir Charles Parsons had done, starting with a little 20-h.p. turbine in 1884 and going up to 80,000-h.p. engines in the great cruiser "Lion." Dr. Diesel also had gone a long way towards realizing his dreams. Like Sir Charles Parsons he had seen during his lifetime the development of the Diesel engine and its application to almost every motive power purpose in the world, and he had the greatest pleasure in congratulating him on his wonderful success. He recognized him as one of the greatest inventors at present living.

The idea of compressing air alone into the cylinder and then injecting fuel in either the gaseous or liquid state was not a new one at the date when the author took up his work. In 1887 he

(Mr. Dugald Clerk.)

himself (Mr. Clerk) built an engine in Birmingham of the two-cycle type in which air was sent into the motor cylinder, compressed into a compression space, and a separate pump, which compressed the gas, forced the gas into the cylinder, the gas igniting as it entered the cylinder, and in that way he produced a constant-pressure engine of the type, so far as the thermodynamics were concerned, that was now known as the Diesel type. It differed, however, from Dr. Diesel's engine in using much lower compressions and on igniting the gas-jet as it entered the cylinder by a special form of incandescent tube. He built two engines of that type and ran them in 1888. Thinking that the author would like to see some of the indicator diagrams which he took in 1887 and 1888 he had brought a few of them to the Institution, some of which were reproduced in Figs. 25 to 30 (pages 234–5). They were indicator diagrams showing the action of the flame injection, and there were some governing diagrams showing reduction of the flame-injection into the cylinder. Those diagrams were all taken from an experimental "flame-injection engine," designed by the speaker and built by Messrs. Tangyes, Ltd., Birmingham, at the end of 1887. The engine was of the single-acting two-cycle type, having one motor and one displacer-cylinder, the displacer-piston carried a separate gas-pump piston. The motor cylinder was 8 inches diameter and the stroke 15 inches, the displacer-piston was 12 inches diameter and the stroke 9 inches. The displacer-crank was arranged in advance of the main crank, as was usual on the Clerk two-cycle engines. The gas-pump was operated on the reverse stroke of the displacer-piston, so that, while the air-supply piston was in advance of the main piston, the gas-pump was behind.

The action of the engine was as follows:—The main piston over-ran ports in its cylinder and the displacer discharged air into the cylinder at low pressure (sometimes by way of other ports uncovered by the main piston and sometimes by way of a lift valve at the end); the air was then compressed by the main piston into a compression space; when compression was nearly complete the gas-pump injected compressed coal-gas, so that an advance jet ignited at a specially arranged tube-igniter and produced a flame into which further compressed gas was then injected. By this arrangement a gradual rise of pressure and then a maintained pressure was produced by flame injection. Governing was accomplished by throttling the supply of gas to the gas-pump, so that gas-injection began later and later. Different shapes of combustion space and arrangements of jets were experimented with. This engine was run for six months.

The two diagrams, Figs. 25 and 26 (page 234) showed mean pressures of 32·4 and 33·3 lb. per square inch respectively, giving about 9 i.h.p. at 25·9 cubic feet of gas per i.h.p.-hour.

Fig. 27 (page 234) showed the effect of throttling the gas; the mean pressure was reduced to 10·7 lb. per square inch, and the i.h.p. to 3·6 at 150 revolutions and the gas-consumption became 22·7 cubic feet per i.h.p.-hour.

Fig. 28 (page 235) was also taken at a lighter load, but here some air was taken into the gas-pump along with the gas, and other modifications were made in the flame-jet arrangements.

Figs. 29 and 30 were taken under other circumstances as noted. Pump taking gas only. Cone back cover, gas-jets, no air by induction or otherwise. This formed one of many experiments.

The diagrams all showed clearly the slow pressure rise and the sustained pressure during the early part of the stroke and also the fall to atmosphere when the main piston over-ran the ports. That engine from a running point of view was very good, but greater economy could then be obtained with explosion instead of constant pressure, and therefore the matter did not go any further at that time. It led him, however, to take a greater interest in the constant-pressure engine, although in an early Paper to the Institution of Civil Engineers, in 1882, he developed its theory fully and showed the laws necessary to be observed to obtain the highest efficiency possible. On the formula developed by him in 1882, and explained in his book in 1886, he had calculated out the air-cycle efficiency of the Diesel engine, and had found that if the air-cycle efficiency was calculated out from its compression space, the present Diesel engines, if they lost no heat at all and had air alone as the working fluid, would have a theoretical efficiency of 0·56.

(Mr. Dugald Clerk.)

8-*inch* × 15-*inch Flame-Injection Engine*, 1888.
Indicator Diagrams Original Size.

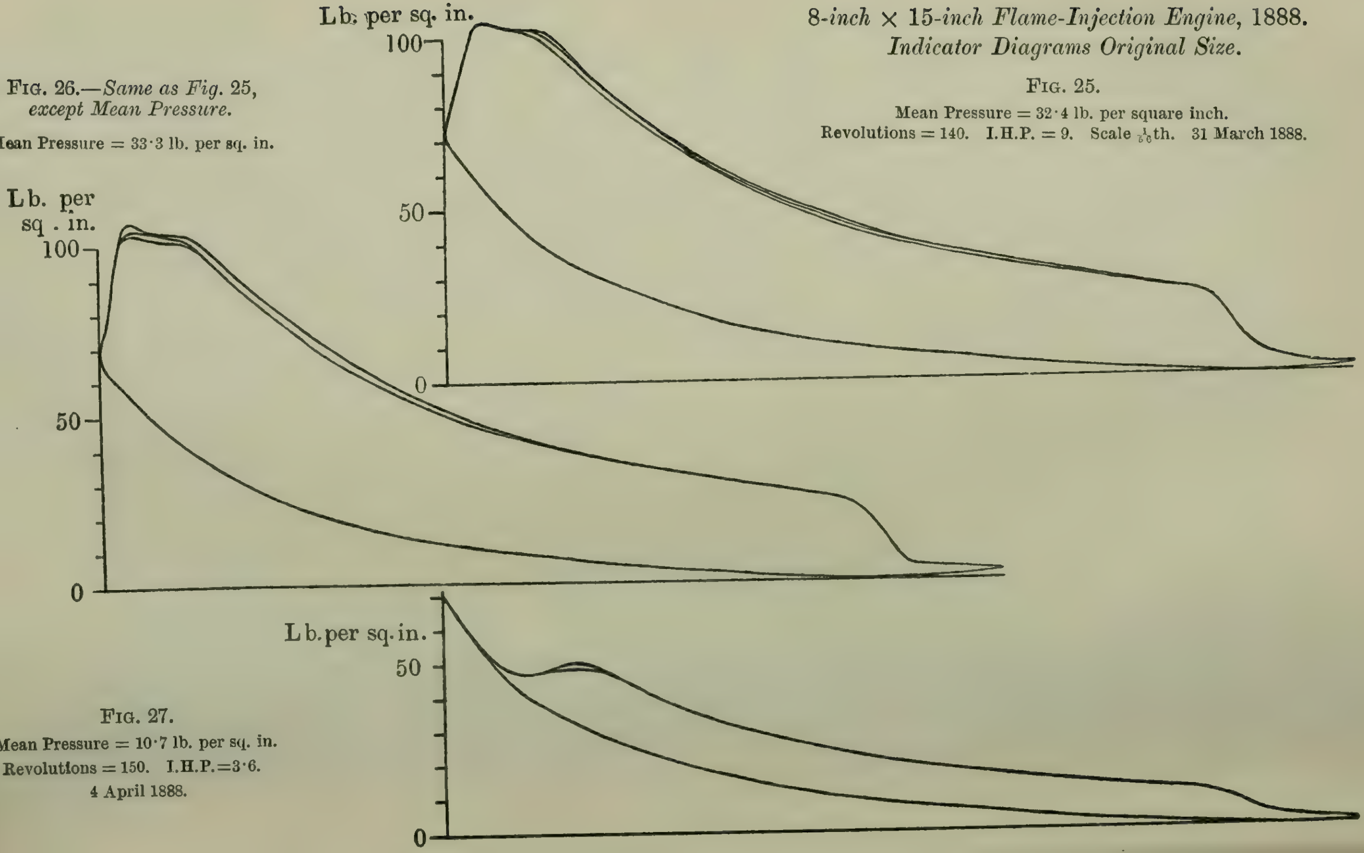


Fig. 25.

Mean Pressure = 32·4 lb. per square inch.
Revolutions = 140. I.H.P. = 9. Scale $\frac{1}{6}$th. 31 March 1888.

Fig. 26.—*Same as Fig.* 25, *except Mean Pressure.*

Mean Pressure = 33·3 lb. per sq. in.

Fig. 27.

Mean Pressure = 10·7 lb. per sq. in.
Revolutions = 150. I.H.P. = 3·6.
4 April 1888.

8-*inch* × 15-*inch Flame-Injection Engine*, 1888. *Indicator Diagrams Original Size.*

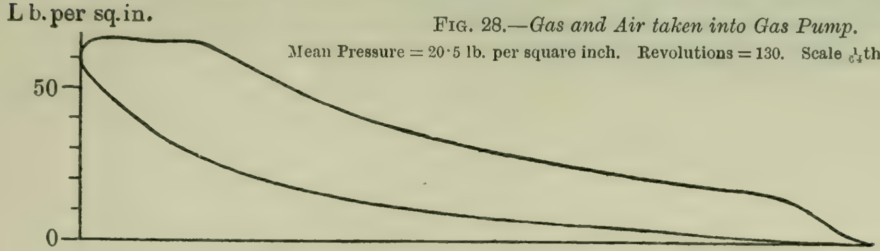


FIG. 28.—*Gas and Air taken into Gas Pump.*

Mean Pressure = 20·5 lb. per square inch. Revolutions = 130. Scale $\frac{1}{64}$th. 9 June 1888.

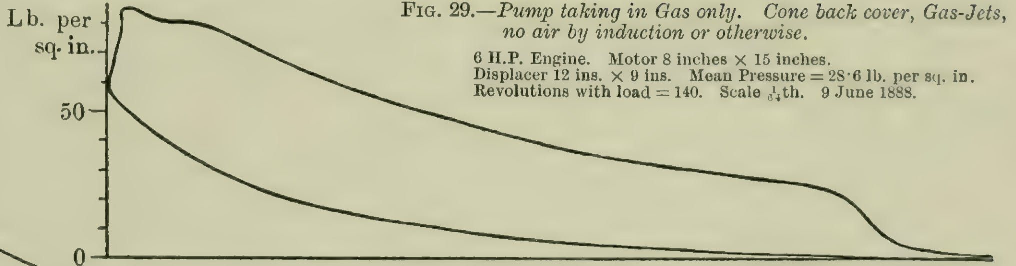


FIG. 29.—*Pump taking in Gas only. Cone back cover, Gas-Jets, no air by induction or otherwise.*

6 H.P. Engine. Motor 8 inches × 15 inches.
Displacer 12 ins. × 9 ins. Mean Pressure = 28·6 lb. per sq. in.
Revolutions with load = 140. Scale $\frac{1}{64}$th. 9 June 1888.

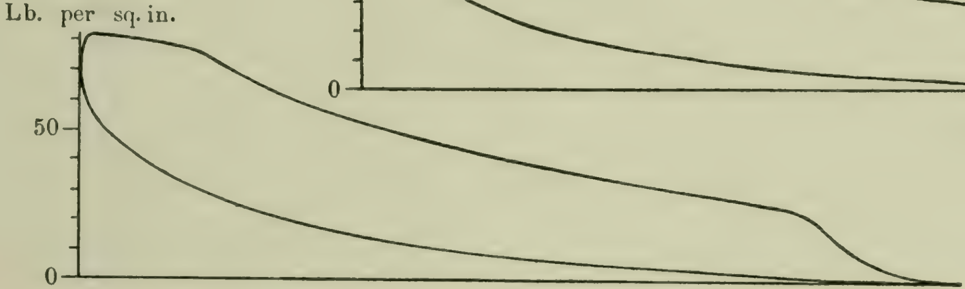


FIG. 30.—*Similar to above.*

9 June 1888.

(Mr. Dugald Clerk.)

Another experimental engine (altered from an ordinary Clerk cycle engine) was tested towards the end of 1887. Its main cylinder was 10 inches diameter and 12 inches stroke. This engine was operated by flame-injection.

Some of the results obtained by Dr. Diesel and others had seemed to him to give indicated efficiencies which were too high. What he was about to say was a mere scientific criticism, but it was interesting. He had always considered that the published indicated efficiencies of the Diesel engine were almost all too high, and the reason for that was as follows. In calculating the indicated power of the Diesel engine the positive diagram above the compression was taken for the mean pressure. That positive diagram, however, included a proportion of work which was given to it by the high-pressure compressed air coming from the compressing pumps. On the Continent Dr. Diesel and other German engineers had always considered that that was a friction loss which should go into the mechanical efficiency. On that point he ventured to differ from Dr. Diesel; he did not think that should be included in mechanical efficiency at all, but should be considered one of the thermodynamic elements. If in that way one calculated a Diesel diagram from the indicated point of view, one would always find one got something under 40 per cent. He did not agree with Dr. Diesel that he had ever got 48 per cent. indicated efficiency as mentioned in the Paper. It did not affect the brake results, but it affected the scientific theory. He was interested for the moment in the pure thermodynamics, and as far as they were concerned Dr. Diesel could not have obtained such an efficiency. Taking 0·56 as the highest air efficiency on the expansions he used, a great many experiments made by English engineers, himself among them, had proved that it was impossible to obtain anything better than 0·7 of the theory; and multiplying 0·56 by 0·7 produced something like 0·39. Therefore Dr. Diesel had obtained the very high indicated efficiency of about 39 to 40 per cent., but the 48 per cent. mentioned in the Paper was erroneous. That could be examined into very easily by taking the ordinary method of determining efficiencies, the final method that had to be ultimately appealed to, and that was the brake power developed for a given consumption and given heat units. In that way it would be found that the Diesel engines gave a brake efficiency of about 30 per cent. For instance, taking an engine that was tested by Mr. Longridge in 1905, the Carel Frères engine which had been shown on the screen, that gave oil per b.h.p. at not quite full load about 0·444 lb., and from the thermal value of the oil he calculated the brake thermal efficiency at 29½ per cent. The indicated thermal efficiency of the engine he made to be 38½ per cent.—a very high efficiency. In 1908 an American Diesel engine gave a test of 29·2 per cent. brake efficiency, and another American Diesel engine gave 28·1, and a recent test on a Mirrlees-Diesel engine made in Stockport gave 31½ per cent. He thought he might say that the usual maximum brake thermal efficiency of a Diesel engine ranged from 29 per cent. to 32 per cent.

He wished to say a word in favour of the other form of internal-combustion engine, the gas-engine. Although he was interested in the Diesel engine, his main interest perhaps was still in the gas-engine. It was possible to get from any good gas-engine, with a compression ratio of about 5½, 30 per cent. of all the heat which was given to the engine cylinder, in brake horse-power, and at this compression ratio an indicated efficiency of 35 per cent. could be obtained. That was in an engine which was not compressed high enough to pre-ignite. By taking some precautions, such as mixing with exhaust gases, a thing he had often done, or injecting water spray, it was possible to run up the brake efficiencies to 33 and even to 34 per cent. with the gas-engine. There were no commercial gas-engines giving 34 per cent. regularly because the compressions were somewhat too high, but 32 per cent. could be obtained as a regular thing.

He differed from the author in thinking that there was any special economy from a thermodynamic point of view in the Diesel type of engine. The great advantage of the Diesel type did not lie in that but in its capacity to burn crude oils. He would undertake to build a compression gas-engine with an expansion sufficiently long to give any thermal efficiency, either indicated or brake, which the author could do by using the Diesel type, and he

(Mr. Dugald Clerk.)

TABLE 1.

Weights of Large Continental Gas-Engines of the Tandem Double-Acting Four-Cycle Type.

B.H.P.	Net Weight of Engine with Fittings but without Fly-Wheel.	Net Weight of Fly-Wheel.	Weight of Engine per B.H.P.	Weight of Fly-Wheel per B.H.P.
	Tons.	Tons.	Lb.	Lb.
2,000	266·5	—	298·5	—
1,500	162·3	34·5	242·5	51·3
1,060	109·3	—	231·0	—
1,000	120·0	—	269·0	—
950	95·1	25·0	224·0	58·8
800	85·0	—	238·0	—
750	68·5	17·7	204·5	52·6
700	81·7	15·7	261·0	50·2
630	66·5	—	237·0	—

would use the explosion method only. Of that he had no doubt whatever. But to do so he would require to build a very much heavier gas-engine than was at present built in good commercial practice. The author's engines were very much heavier than those of the ordinary type. The engine weight, in the early engines, as given in the Paper, was about 500 to 600 lb. per b.h.p., and in the high-speed engines 110 b.h.p. Remembering those weights he would like the members to look at three or four lantern slides he had brought with him, and which were reproduced in Tables 1 and 2 and Figs. 31 and 32.

Fig. 31.

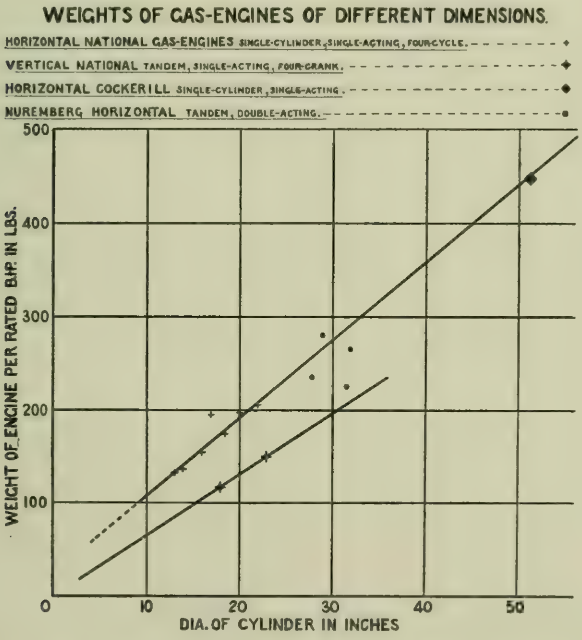


Table 1 was interesting as showing the reasons for going to the two-cycle engines. It showed a number of Continental engines of different powers, giving the total weight of the engine and the weight of the fly-wheel per b.h.p. It would be noticed that the Continental engines, tandem, double acting, varied from 237 lb. at 630 b.h.p. up to 298 lb. at 2,000 b.h.p.

(Mr. Dugald Clerk.)

Fig. 31 was plotted to show the characteristic of all engines, namely, that as the cylinder diameter increased, the weight increased per b.h.p. It showed a number of recent "National" horizontal single-cylinder gas-engines, and the upper line represented the weight for certain cylinder diameters. A 20-inch cylinder gave an engine which weighed close on 200 lb. per b.h.p., and a Cockerill engine with a 51¼-inch cylinder required over 440 lb. per rated b.h.p. A straight line drawn through the weights of the smaller cylinder engines passed through that of the large Cockerill engine. The "National" vertical tandem engines of about 22 or 23 inches cylinder gave 110 lb. weight per rated b.h.p. as shown on the lower line. An engine on the single-cylinder four-cycle system required a very great weight for a given power; as the cylinder increased the weight per h.p. increased rapidly. He thought that was the reason why Dr. Diesel found it necessary to go to the two-cycle type to reduce weight per h.p., and he (Mr. Clerk) was

Fig. 32.

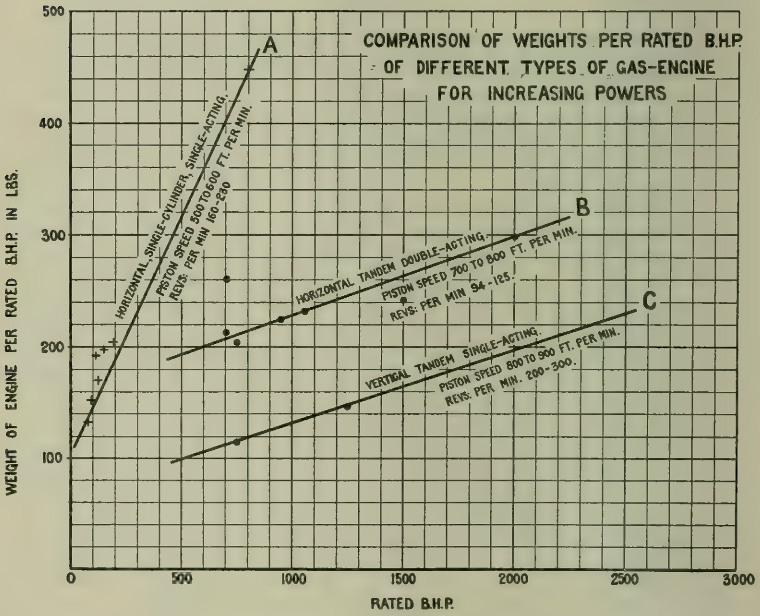


TABLE 2.—*Particulars of Gas-Engines of Different Dimensions and Types.*

Rated B.H.P. with Coal-Gas.	Diameter and Stroke.	Stroke Bore Ratio.	Revolutions per Minute.	Piston Speed.	Weight of Engine.	Weight per B.H.P.
	Horizontal "National" Gas-Engines, Single-Cylinder Single-Acting Four-Cycle.					
	in. in.			Ft. per min.	Tons.	Lb.
57	13 × 20	1·538	230	498	3·33	131·0
68	14 × 21	1·500	230	537	4·08	134·5
85	16 × 22	1·375	210	500	5·82	153·5
105	17 × 26	1·530	190	539	9·08	193·5
125	18·5 × 28	1·513	180	555	9·48	170·3
150	20 × 31	1·550	170	567	13·20	197·7
185	22 × 34	1·545	160	587	17·05	206·5
Rated B.H.P. with Blast-Furnace Gas.	*Horizontal Cockerill, Single-Cylinder Single-Acting Four-Cycle.*					
800	51½ × 55	1·07	75	470	160	448
	Horizontal Continental, Tandem Double-Acting Four-Cycle.					
800	28 × 34	1·21	130	736	85	238
1,000	32 × 40	1·25	110	733	120	269
	Vertical "National" Gas-Engines, Tandem Single-Acting Four-Cycle.					
750	18 × 18	1·00	300	900	39	116·5
1,250	23 × 24	1·00	200	800	83·5	149

(Mr. Dugald Clerk.)

very glad that Dr. Diesel had done so, because as one of the early inventors of the two-cycle engine he had a special scientific interest in seeing the two-cycle adopted.

On Fig. 32 the weights per b.h.p. were plotted against the b.h.p. for :—A. Single-cylinder single-acting engines; B. Tandem double-acting engines; and C. Vertical single-acting tandem National engines.

Table 2 furnished particulars of gas-engines of different dimensions and types. It would be noticed that at 800 h.p. in the single-cylinder single-acting type the weight was 448 lb. per b.h.p. Taking the horizontal double-acting tandem at 800 h.p. the weight was only 238 lb. In the vertical tandem engine, the National, with the same power there was only 116 lb. The author's engine of 800 h.p. (he thought it was 200 h.p. per cylinder) would come somewhere considerably heavier than any of the engines shown; on the scale it would come somewhere at 600 lb. That showed that there must be a reason for building the Diesel engine so heavy.

Without going into any other matter, it would be seen how necessary it was to get away from the single-acting four-cycle type. By having double-acting two-cycle engines such as were being built at Nuremberg, the weight could be reduced for an engine of the same speed to 238 lb. per b.h.p. The recent engines the author had referred to, those of 116 lb. weight per b.h.p., were high-speed engines.

There was a difficulty which he would like the author to clear up. The author had managed with great engineering ability to go up quite safely to 23 or 24-inch cylinders, but in designing a Diesel engine one had to design not only for the 500 lb. per square inch in compression, but also for what was known as pre-ignition in ordinary gas-engines, where the design was for 400 lb. per square inch and 120 lb. more allowed for pre-ignition; that is, the design was for 520 in the ordinary gas-engine cylinder. But in the Diesel engine, as far as he understood the difficulties of designing, it was necessary to design for 1,000 lb., although the maximum pressure ordinarily was only 500 lb., because if by any chance the inlet valve became stuck up and an inflammable charge happened to get into the cylinder during the compression stroke, explosion would ensue instead of combustion and there might be an accident. 999 times out of a thousand the Diesel engine was compressing air, but if anything happened to go wrong so that explosive mixtures might be compressed, unless enough metal was provided there would be a bad accident. Dr. Diesel had provided enough metal in the smaller engines, but he did not quite see how he could do it in the large cylinders, and that was the difficulty in going beyond 24 inches. He understood that there was an engine with cylinders about 31½ inches diameter, but if he were working with it he would be very cautious, and it would be interesting to know if there were any safety arrangements to get over the difficulty of a sticking valve. The author perhaps would pardon him for mentioning one or two of the difficulties of the engine, because as an old engine designer he thought of all those things, and he would be glad if the author could clear up one or two of the points showing what methods he intended to adopt to get safely up to the large cylinder of 30 and 40 inches diameter. The difficulties of the ordinary gas-engine design for 500 lb. maximum pressure per square inch were sufficiently great, but it seemed to him that the difficulties in connection with the large cylinders for the Diesel engines were still greater. In conclusion, he thanked the author very heartily for his most valuable Paper.

Mr. BASIL H. JOY wished it to be understood that he was a keen advocate of the engines coupled with the name of the author, who, he considered, had given the marine engine the only possible chance of being of the internal-combustion type. There were one or two questions in connection with the Paper which he wished to ask. First, could the author give a correct explanation of the serious accident which happened to the M.A.N. engine a short time ago when about a dozen men were killed? A knowledge of the cause would enable better provision against such accidents to be made in the future. The second question he had to ask also had in view the good of the industry which was growing up so rapidly: Was it a fact that the engines of the large French auxiliary Diesel "Quevilly" were about to be, or had been, taken out of the ship? He was quite aware that the owners had ordered another ship, but

(Mr. Basil H. Joy.)

it was rumoured that the engines were about to be taken out, not on account of any fault of the engines but because the propellers had been found to cause a serious drag on the ship. He sincerely hoped that was not so, because there was no doubt that the Diesel engine as an auxiliary had a magnificent scope.

There was one point which occurred twice in the Paper. On page 196 the author said that "the two-stroke cycle engine with its smaller cylinders has now come into favour for stationary plants of higher horse-power, and, as a marine engine, is likely to become the standard type." Again, on page 201 he said that engineers were for navigation purposes inclined to abandon the four-stroke cycle engine entirely. He thought that required a little qualification, though perhaps the author would correct him if he was wrong. It was perfectly true that the greater part of the Continental Diesel engine builders were building two-cycle engines—he could quote eight or ten of them—but it was equally true that there were no large two-cycle engines afloat in the waters of Western Europe at all events, as far as he knew, whereas there were at least three ships of reasonable power afloat in those waters on the four-cycle. He had to confess he had no knowledge as to whether the engines built by Nobel's were two- or four-cycle. There were, however, sixty to seventy French submarines of 600 to 7,000 h.p., as stated by the author, and he believed those were entirely on the four-cycle. Therefore the author's remark in the Paper seemed to require a little qualification.

He believed that some of the difficulties that had been met with in connection with the two-cycle engine had been due to the fact that weight cutting had been carried to an enormous extent, and that the makers of the four-cycle engine had erred in the opposite direction. The four-cycle engines he had seen were very heavy, which did not seem to be altogether a fault, at any rate for commercial purposes. The two-cycle engines were being used in Germany, particularly for submarines, and the weight had been cut to a considerable extent.

He would also like to know whether the author could give any information with regard to the difficulties of the double-acting engines; for instance, did the horizontal fuel-valves in the bottom of the cylinder cause any difficulty, or the fact that there were two valves with a rod in between them? In view of the small engines that had been shown in the illustrations, he thought the high-pressure compressor to give 900 lb. to the square inch was a somewhat elaborate and proportionately costly thing for a small engine, and he would like to know whether the author could give any information about the American devices that had been produced to take the place of the compressor. One of those devices consisted of a little plunger in the cylinder-head, tripped by a cam-gear, and projected to the opposite end of its cylinder at great velocity; the other was a projection on the top of the piston which fitted into a recess in the cylinder head, with a smaller clearance than that in the main cylinder, and so compressed the air to high pressure. There might be difficulties, and perhaps the author could say what his experience had been.

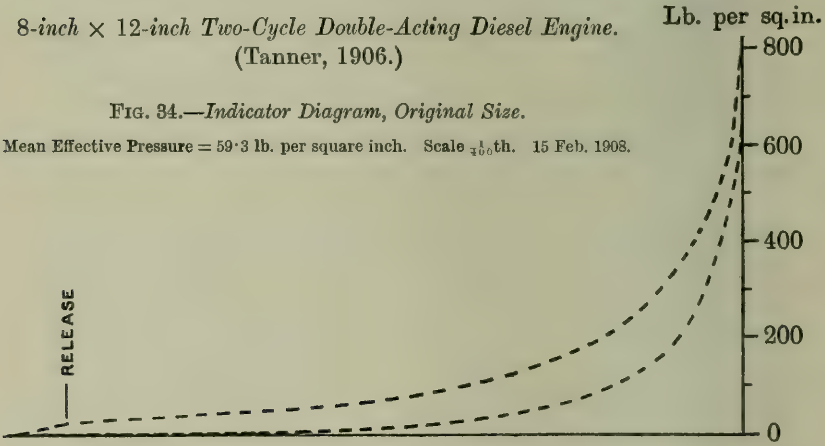
Also, could the author give an explanation of exactly what was the difference between the Diesel engine and the Sabathé engine, which it was claimed carried out its combustion partly at constant volume and partly at constant pressure, whereas the Diesel was constant pressure? Was it a fact that if fuel was admitted earlier in the Diesel engine it would produce exactly the same result? At the same time the Sabathé engine was an economical one. He had the official Admiralty ten-hours' test in which the consumption was given as 0·39 lb. of paraffin per h.p. per hour at full load and 0·44 at $\frac{5}{8}$ load. It appeared to him that the fuel admission-valve in the Sabathé engine would actually supply the fuel in two doses, the first of which would give combustion at constant volume, and the second at constant pressure.

His last question was: Could the author say how long one of the Diesel engines would run on the tar-oils he had given in his list as being suitable for combustion? The "Vulcanus" had a good deal of trouble with gumming of her piston-rings through dirty oil, whereas the Barclay Curle single-cylinder engine ran for thirty days without a stop on Shale oil, and on examining the piston on the conclusion of the run, as far as he could see it was in

(Mr. Basil H. Joy.)

a condition to run a considerable time longer. He would like to know how tar-oils compared with Shale oil.

Mr. H. ADE CLARK said that, having heard Dr. Diesel on the history and progress of the Diesel engine with great pleasure, he would like to add a little history. In 1902 he attacked what he then regarded as the extravagant claims made for the Diesel engine; and in 1903 he gave to the Institution a Paper * containing the details and results of his investigations which very completely vindicated those claims. Some of his statements were severely criticized by some members of the Institution who had since taken up the manufacture of the Diesel engine. In 1906 Mr. F. H. Tanner, of Bristol, filed his complete patent specification for a two-stroke double-acting type of Diesel engine [No. 23104, 1906], and in 1907 he invited the speaker to test one of these engines, Fig. 33, Plate 8, having a cylinder 8 inches by 12 inches. Fig. 34 is taken from an indicator diagram then made. He, the speaker, thereupon advised the inventor to find means to build a larger engine with more perfection of detail. It had taken Mr. Tanner until July 1911 to find a British firm to consider seriously the



8-*inch* × 12-*inch Two-Cycle Double-Acting Diesel Engine.*
(Tanner, 1906.)

FIG. 34.—*Indicator Diagram, Original Size.*

Mean Effective Pressure = 59·3 lb. per square inch. Scale $\frac{1}{100}$th. 15 Feb. 1908.

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* Proceedings, 1903, Part 3, page 395.

designs of his engine. The firm, Messrs. Workman, Clark and Co., of Belfast, asked the speaker to report on the designs for a three-cylinder two-stroke cycle engine in August 1911, and they now had the first element of the three-cylinder set well under way.

The main characteristics of the engine were as follows:—

It would run on the Diesel principle of injecting the fuel-oil into the highly compressed and very hot air, resulting in combustion at constant pressure, followed by expansion during the greater part of the working stroke; near the end of the stroke the piston uncovered ports in the cylinder through which the exhaust escaped. A little further on the piston uncovered the scavenging ports when scavenging air supplied by a turbo-blower would sweep out the cylinder and supply air for the up-stroke or compression stroke, at the end of which the fuel-oil would again be injected.

The starting of this engine would be by compressed air, and the fuel injection by compressed air. The features in which it would differ mainly from the Continental engines was in the great simplification of the valves, and consequently the reversing arrangements.

When running as an oil-engine there would be but one working valve, namely, the oil-injection valve. When reversing, this valve only would have to be put out of action and the compressed air brought into action through a hand-operated control-valve, and entering the cylinders through automatic starting valves. The control valve was a continuously rotating valve divided longitudinally into two parts, one of which would distribute compressed air for starting the engine ahead, and the other part would perform the function for starting the engine astern. The fuel cam at the same time automatically took up its position for ahead or astern running. The starting of the engine would be carried out by hand through a lever and wheel; the lever was pulled over disengaging the fuel cam and its operating lever. The starting wheel was then turned in the direction in which it was desired to run the engine; this movement resulted in the opening of a valve permitting the compressed air for starting to have access to the corresponding division of the rotating valve, which then distributed it to the

(Mr. Ade Clark.)

cylinders in the correct order. The engine having started, the fuel cam was thrown into action, and the starting wheel returned to its normal position, thus putting on the fuel and cutting off the compressed air. The usual parts would be water-cooled and the lubrication forced. It was the extreme simplicity of the starting and reversing arrangements made possible by the elimination of exhaust and scavenging valves which gave such great promise to this engine as a marine motor.

When one compared this with the elaborate reversing mechanism of the four-cycle types of marine engines, it was very surprising that this design was not earlier taken up by English makers. For though it was obvious that a good deal of experimental work of adjustment would be necessary with the details to get the best results and attain complete reliability, it was equally plain that the resulting engine would be exceedingly simple, and its development into double acting—a very much simpler matter than with any other type yet proposed.

As the Paper had dealt with types—not details, he would refrain from going into details now, in the hope that later he might present to the Institution a Paper on this Tanner-Diesel engine, including results of working. As the result of his studies and investigations of the Diesel engine in 1902–3, he acquired a great admiration for Dr. Diesel and his engineering colleagues for the conception of the engine, and more so for the great work of experimental determination of the best conditions. The results of recent work in the marine sphere had strengthened this feeling, and he took this opportunity of offering his sincere congratulations on the great success of their work.

Mr. MARK ROBINSON (Member of Council) said time did not permit a repetition of the compliments which such an important Paper deserved, a Paper important not so much for the novelty of its conclusions as for the force with which they were put forward and for the array of facts and statistics which illustrated and supported it. Speaking as one who had actually engaged in the manufacture of Diesel engines he saw there was much in the Paper which called for comment, chiefly favourable comment, but the lateness of the hour precluded any detailed treatment. There was one matter, however, which was fully dealt with in the Paper, but had been almost entirely passed over in the reading of it, which seemed to him to be of very great importance and interest, and he hoped that some who were more conversant than himself with the secondary products of coal would speak upon it. It was evidently claimed for the Diesel engine that it was not only the best engine where coal was scarce or not to be had, but that it was also the best engine even where coal was plentiful. It was broadly claimed that a ton of coal could be more economically used in making gas for a gas-engine, tar for a Diesel engine, and coke for other purposes (besides other by-products), than by burning that ton of coal directly in a furnace. If that view were well founded, it was of the very greatest importance, and the most serious attention should be directed at once to the subject.

Mr. H. S. RUSSELL (Stockport) said it was not altogether to be wondered at that the Paper was chiefly a record of what had been done in Diesel engines by Continental makers, and that very little was said about the English makers. Much of the Paper was historical, and to that information he might add that the first Diesel engine made in Great Britain was made by Messrs. Mirrlees in Glasgow in 1897, the same year that Dr. Diesel mentioned for his first successful engine. That engine was working now most satisfactorily. It was removed about four years ago and re-erected at Stockport, and it was in constant use at the present time running a compressor used for charging air-reservoirs. It was quite a small engine, practically the same size as the one shown by the author—10-inch cylinder and 16-inch stroke, running at 200 revolutions, and giving about 20 b.h.p. It was tested in the early part of 1898 by Professor W. H. Watkinson, and it gave a thermal efficiency (i.h.p. to thermal units in the fuel) of 38·6 per cent., and a fuel consumption of 0·5 lb. of oil per b.h.p.-hour with oil having 17,800 B.Th.U. per lb. The efficiency of the coal consumption was practically as good as anyone could get now with an engine of that size.

(Mr. H. S. Russell.)

It was often stated that the British manufacturers of Diesel engines were a long way behind the Continental makers, but he denied that entirely, as it was not a fact. British engineering was as good as any engineering in the world. It might perhaps be a fact that in some ways British manufacturers were not quite so reckless. The author had mentioned that there were no Diesel engines in the English section of the Turin Exhibition, and he deduced from that that England had still very little interest in the Diesel engine. It was not want of interest in the Diesel engine at all; it was want of interest in Turin. His firm had had the question of exhibiting in Turin very carefully before them, but they were so full of work and saw so little prospect of doing a big business in Italy with British-made engines that they did not think it was worth the expense of exhibiting.

A good deal had been said about the large engines that were being built on the Continent. He had to confess that the largest engine his firm were building at the present time was 750 h.p., but it was built with cylinders of sizes that had been tried for a long time and proved perfectly reliable. Could the same be said of the large engines which had been shown in the Paper?

Some little time ago an official of the British Government went abroad to investigate the Diesel engine question, and travelled all over the Continent and saw the various types of engines that were being made. He (Mr. Russell) was told by that official on his return that he had satisfied himself the Continental makers of Diesel engines had not got any further than the British manufacturers—except on paper.

Fig. 24, Plate 8, showed a picture of a 1,200 h.p. single-cylinder Carels engine, but it did not look like a photograph of an engine in actual work as there was no connecting-rod.

There were some British people, especially Municipal Councillors, who were too easily taken in by the boasted Continental superiority. He knew of four cases quite recently where Municipalities were buying Diesel engines, and he knew that the engineers and the Chairmen, and sometimes some of the Councillors, had a nice trip on the Continent going round the Continental works seeing the

Continental Diesel engines, and they eventually bought the Continental Diesel engines. Those very gentlemen had no time to go to British works to see what the British firms were doing, although a special invitation was extended to them. If there had been time, he could mention improvements in the Diesel engine which had been introduced by British manufacturers—improvements which the Continental firms had been only too glad to adopt. The high-speed engines to which the author referred were really in the first instance developed by a British firm, and there were about twenty or thirty of them at present working on battleships and cruisers, and several others were on order for the new naval programme. They were not the open type with light steel columns, but crank-chamber engines, totally enclosed, and with forced lubrication throughout, and the records showed that many of them did continuous runs for no less than 900 hours on end, or for more than five weeks day and night without stopping.

The two-stroke and horizontal engines were not altogether new. There were two-stroke engines made eleven years ago and strangely enough they were of the horizontal type. One of them was shown at the Glasgow Exhibition in 1901. They were not altogether satisfactory, but he did not say that was the fault of the makers of the engine. It was supposed that the weight of a two-stroke cycle engine must be less than that of a four-stroke cycle; everybody seemed to take that for granted; why, he did not know. One friend of his, who had considerable experience with both two- and four-stroke cycle engines for the same purpose and the same power, told him that, although the makers promised a great reduction in weight, when he received the two-stroke cycle engine it weighed as much as the four-stroke cycle. He was not sure that the expected saving of cost in the two-stroke cycle engine was not also illusory. The limit in a Diesel engine of the power to be obtained from the cylinder was determined, like all internal-combustion engines, by the heating in the cylinder. A certain amount of heating was allowed, with a margin, and that determined the power. It was very attractive to think that, by using a two-stroke cycle, double the horse-power could be obtained, but if double horse-power were

(Mr. H. S. Russell.)

obtained, double the heat was being generated, and if the engine was already being worked to the safe limit of heat in the cylinder, it would be necessary to run at half the speed, so that he did not see there would be any gain in weight. Probably there were some factors in the matter of which he was unaware, and about which the author might enlighten him.

As to the horizontal engines, he would much like to know if anyone could say why that type had been adopted. He could not see any advantage in it, but a great deal of disadvantage. He thought the real answer was given by the author himself on page 203, where he said, "The fads, habits and tastes of the purchasers, and the kinds of machine tools in use in the works, have to be taken into consideration rather than technical points of the engine itself."

Mr. E. R. BRIGGS desired to say a word or two about the future development of the Diesel engine in this country. He thought it would develop very largely on two lines, that of the marine engine and that of the land engine, namely, the central power-station engine for electric driving. With regard to the marine engine, he thought from what the author and others had said, the engine of the future was likely to be a two-cycle engine and not the four-cycle. Considerations of weight—he thought the engine would be lighter in spite of what had been said—and also considerations of reversal made that an almost undoubted point. Also he thought the engine would be of the cross-head type, because the advantages of the cross-head over the trunk-piston type were enormous. Very few objections could be made against it, except perhaps the one of cost, and opposed to that there were a number of very sound reasons. The cross-head engine would allow of an enclosed crank-chamber being used, which would permit of proper lubrication of the working parts. The piston itself would also be of simpler construction, as it would not be required to act as a cross-head. The cross-head engine also would allow of a diaphragm being placed across the top of the crank-chamber and water-cooled pistons being used—an enormous advantage over oil-cooled pistons. One of the great disadvantages of the enclosed crank-chamber trunk-engine was the fact that carbonized oil found its way into the crank-chamber, and when the oil was used with forced lubrication the small particles of carbonized oil found their way back into the bearings. The cross-head engine would gain in the fact that it would not require so much space for the pistons.

With regard to the central-station engine, the Willans-Diesel, like most other Diesel engines in this country, had been developed on the original Continental lines, that is, the ordinary trunk-piston type of a four-cycle engine, up to about 150 b.h.p. per line. The question of future development was a matter which was receiving very careful consideration at the Victoria Works, Rugby, but, in determining what lines the design would follow, one was influenced by a large number of factors, several of which were entirely outside the control of the manufacturer. In the first place a manufacturer had to remember that he had to make engines at a profit; he also had to bear in mind that, no matter how good an engine he might develop, unless he could produce an engine that agreed with the fashion of the time he would stand little chance of making anything but a loss.

Another important factor was that Great Britain was the home of the vertical high-speed steam-engine, and central power-station engineers had had that engine almost exclusively until within the last ten years, when it was superseded by the steam-turbine. He thought, therefore, that the engine would be undoubtedly of a vertical type, and would have an enclosed crank-chamber and necessarily forced lubrication. Whether or not it would be of the cross-head type depended very largely upon the customers themselves. There was no doubt that the cross-head engine was a far superior engine to the trunk-engine, for the reasons he had just mentioned, in connection with marine engines; but, on the other hand, the cross-head engine could not be manufactured for the same price as the trunk-engine, and if central-station engineers insisted, as they frequently did, on accepting the lowest tender irrespective of every other consideration, it was likely that the cross-head engine would stand very little chance of development in this country. In that respect the manufacturers were in the hands entirely of the central-station engineers.

(Mr. E. R. Briggs.)

Another point which seemed frequently to be overlooked was the question of labour. Labour in this country was dearer than on the Continent and cheaper than in America. As a natural consequence the automatic machine-tool was developed less in this country than in America, and also greater probably than on the Continent. The influence of the automatic machine-tool was written over the whole of the face of the carefully-studied design of any engine or machine. The British engine would develop according to the standard workshop practice of this country, and would be guided to a large extent by a vertical high-speed engine, and also by the demands of the central power-station engineers.

Dr. DIESEL thanked Mr. Dugald Clerk for his kind words, and said he recognized that Mr. Clerk had done a great pioneering work for the advance of the internal-combustion engine, and he himself had derived great profit from Mr. Clerk's work. He had been very pleased to see the diagrams shown that evening, and was bound to say they were very similar to the Diesel engine diagrams, although made many years before. However, as Mr. Clerk had stated himself, his engine differed from the Diesel engine in using much lower compression and on igniting the gas-jet artificially. These two differences were in fact of the utmost importance; they were the real reason of the high efficiency of the Diesel engine and of its practical simplicity, also of its possibility of using all kinds of fuel, and of its high mean pressures of about 110 to 120 lb. per square inch as compared with 32 to 33 lb. in the Clerk engine.

He remembered that during the hard work attendant on his invention and of the first experimental work, when his engine was not running, he sometimes took up the specifications of Mr. Dugald Clerk and studied them to find out how the latter had made his engine run. With regard to the theoretical remarks Mr. Clerk had made, he was entirely of the same opinion that the engineers in Germany were not working out the indicated or thermal efficiency rightly; he was one of the few engineers in Germany who were of Mr. Clerk's opinion, and had laid down his views on the subject in the "Zeitschrift des Vereins deutscher Ingenieure," 1905, p. 814. But the Society of German Engineers had decided to take simply the i.h.p. of the diagram and the b.h.p. and divide the two, and obtain the efficiency in that way. The reason was that it simplified the question of practice. But as Mr. Dugald Clerk has stated, this question was a mere scientific one and did not affect the figures of the real or brake efficiency, on which everybody was thinking alike. It was true, as Mr. Clerk had said, that gas-engines to-day were approaching in a few cases the efficiency of the Diesel engine, but it was not the case fifteen years ago when the first Diesel engines were made. Then the efficiency of the first Diesel engine was nearly double that of the gas-engine; and he thought the results of the Diesel engine had contributed in a very marked way to the advance of the gas-engine. But the gas-engine and its explosion principle was not capable, even in our days, of using crude fuels, as the Diesel engine did; a gas-engine for liquid fuels would have to gasify the fuel in gas generators with a loss of 20 to 25 per cent., so that the comparative efficiency would be 75 to 80 per cent. of the Diesel with the same fuel; that lay not in the thermodynamic point of view but in the principle of the Diesel producing red-hot temperatures by compression of pure air only, and, by this way, of combining the gas generating with the working process in the cylinder itself on a very small quantity of fuel in each single stroke. The author desired to acknowledge the great merits of Mr. Dugald Clerk's development of the two-cycle engine, and to remind the members that he (the author) five years ago had caused the first original engine of Mr. Clerk to be placed in the German Museum of Masterpieces of Science and Technics in Munich.

With regard to the introduction of little plungers in the cylinder-head which were to take the place of the compressor for the fuel injection, these had now all been abandoned as complete failures.

With regard to Mr. Joy's remarks (page 243), he thought the reasons for the Nuremberg accident had not yet been sufficiently settled to speak about it. He was nominated as an expert on the question and was cognizant of all its details, but thought it would hardly be wise to say anything public now. He could mention one thing with certainty, namely, that there was nothing in the system

(Dr. Diesel.)

or principle of the Diesel engine that had caused the accident. The accident occurred in the scavenging pipe or the low-pressure part of the engine, which had nothing whatever to do with the Diesel principle and where no one would have thought an accident was possible. He did not know whether the engines of the "Quevilly" had been taken out, and, if so, that they were taken out on account of the propellers. He had mentioned in the Paper the resistance of the propeller, which took a half-knot off the speed of the ship when sailing. That information was three or four months old, and it might be that some change had taken place, but he did not know about it.

With regard to the question of the two-cycle *versus* the four-cycle engine, that was a subject too long for a short discussion. It should be remembered that everything was in the process of development. Some manufacturers were making four-stroke cycle engines for marine work and others were making two-stroke cycle, and experience would ultimately decide the point; but most of the manufacturers were tending towards the two-stroke cycle for marine work, and all the experimental work on large cylinders for marine engines, mentioned in the Paper, were exclusively on the two-stroke cycle, also all the newer types of submarine engines.

With regard to the difference between the Diesel engine and Sabathé engine, there really was none; the results were the same. Sabathé divided his injection of fuel into two periods. He had a little rise in pressure at the beginning of the combustion and then the curve of constant pressure arose. It would be seen on looking at most of the Diesel diagrams that it was exactly the same there. The time was too short for dividing the injection of fuel in two mechanically distinct periods, and that was why the Sabathé engine was simply a copy of the Diesel with no original feature at all.

The last question of Mr. Joy concerned the time a Diesel engine would run on tar-oils; the time was exactly the same as with ordinary crude oils. The difficulty of the tar-oils did not lie in the combustion, but in the introduction of these thick oils through very small pipes and valves into the compression space, and in the necessity of a higher igniting temperature. But if the oil was introduced and ignited, the combustion itself was all right. The gumming of piston-rings was not a question of fuel-oil, but of lubricating oil and of proper cooling of piston and cylinder walls.

With reference to Mr. Russell's remarks (page 249), he was sorry not to be able to give more information about English-made engines. He had written letters several months ago to English firms to obtain information which he did not get, but some representatives of those firms were present at the Meeting to-night. The first English Diesel engine was made by Messrs. Mirrlees and Co. in the year 1897 or 1898, after his own (the author's) designs, but Mr. Russell was not there at the time. He had mentioned the engine in the Paper and had said that it was still running. The Mirrlees Co. had then approached Lord Kelvin in Glasgow, who studied the question of the Diesel engine and was the first in England to recognize its importance and he advised them to take up its manufacture. He (the author) had the honour of being received several times by Lord Kelvin when in Glasgow and to discuss with him the whole question of the new motor. He could confirm the fact that a high-speed engine had been developed by the Mirrlees Co. about the same time but independently of Continental firms. The two-stroke engine weighed about 20 per cent. less than the four-stroke engine of the same power, and cost about 15 per cent. less than the four-stroke.

In conclusion, he had to thank the members for their friendly reception, which he did not so much take to himself as to the cause he represented, and to which he had devoted the greatest part of his life. The question would not have reached its present importance if he had not had the good fortune to have the collaboration of the best engineering talent of the whole world, and he had to thank all his collaborators in all the countries for the work they had done and the help they had given in the development of the idea. He invited the British engineers still to continue that assistance, and to help in the further development of the engine in the future, especially for the use of large ships.

Communications.

Mr. M. H. CHURCHILL-SHANN wrote that he felt they were too near the event for any of them to be able to take the correct perspective of the importance of Dr. Diesel's work, and it might be that future historians would regard the economic development of the Twentieth Century to have been mainly the result of the Diesel engine as that of the Nineteenth Century was mainly the result of the steam-engine. The present situation with reference to the Diesel engine reminded one of the situation about 1850 concerning the adoption of the steam-engine. Then, as now, it began to be apparent that a new motive power had arrived that might radically alter the whole aspect of shipping. But, perhaps before this could happen, the Diesel engine must also undergo the same phase of evolution that the steam-engine underwent between 1850 and 1870.

There was a line of development of the Diesel engine which seemed to present considerable prospects of evolution, namely, the semi-Diesel engine. This proposed to substitute ignition by hot plate for ignition by compression, so as to get over the extreme variation of working pressure in the Diesel engine which was the cause of its rather considerable weight for power and high first cost, which were at present its chief disadvantages. The writer did not believe that this reduction of pressure by hot-plate ignition was the true line of advance. It burked the question rather than solved it, and reminded one of the attempts to evolve the steam-engine along the line of superheating and not on the line of higher pressures —John Penn's experiments which were afterwards abandoned. Hot-plate ignition did solve the problem of a cheaper engine, but at the expense of bulk and weight which were of vital importance for what he believed to be the great future use of the Diesel engine. He doubted if sufficient attention had been given to the importance of this great variation of pressure in increasing the first cost of the Diesel engine. This variation was now between 500 and 50 lb. pressure on the working stroke, or as 10 to 1. If this variation could be reduced to 4 to 1, a much cheaper engine could be made.

It was to the solution of what he believed to be the key of this problem that the writer's experimental researches had been directed.

The same problem was found in the evolution of the steam-engine, and with it the solution was compounding. His own experiments had successfully solved the problem of the compound expansion of hot gases. Modern engineers had to be reminded that the real reason why compounding was adopted with steam was that it reduced the variation of stress on the working stroke, and hence reduced the cost and weight of the engine, rather than the additional economy eventually got by compounding. In his experiments the writer obtained about 20 per cent. more economy—23 per cent. was shown in the last and most reliable tests. The means he used to attain this was a fly-wheel gas-turbine, so simple in construction that its cost was hardly more than an ordinary fly-wheel. Having obtained the means for the compound expansion of hot gases, the Diesel engine could be designed to have stage compression in the main compression. It has been found of great use to have stage compression in the air-blast compression, and stage compression in the main compression, coupled with the compound expansion of the hot gases, would (1) Reduce the variation of the working stress by at least one half; (2) Do away with the need for such great refinements in working fits, as with stage compression leaks were not so important; and (3) It would double the number of impulses per revolution. There would not be more working parts. As his exhaust-gas turbine fly-wheel took the part of the ordinary fly-wheel at little additional cost, and with the displacer type of two-stroke Diesel engine, all it would require was a smaller diameter of the combustion cylinder to the same diameter of displacer piston.

There were other advantages of this proposed design, but these were in his opinion sufficient to produce the evolution of the light type of small Diesel engine, which he believed would be the great field for the Diesel engine, quite apart from the question as to whether it would displace the steam-engine as the principal motor for marine purposes. Whether this compound Diesel engine and turbine would give the 20 per cent. additional economy of fuel, or

(Mr. M. H. Churchill-Shann.)

even eventually more than this, did not seem to the writer nearly so important at present as to produce an engine of less than half the weight and cost and double the number of impulses per revolution, but with the great advantages of the Diesel engine in the use of low-grade fuel. He would submit that he had made out a strong case for this particular type of Diesel engine, and would ask Dr. Diesel whether this line of development had been investigated by him or his associates. These experiments were not made on a Diesel engine, largely because the small Diesel engine was not yet easily procurable; but the writer's aim was to solve the problem of expansion on the compound principle, as he saw that this was the key to compounding both compression and expansion. Compounding was the legitimate development of heat engines working on a great expansion, and they could not be made either of light weight or of reasonable first cost in any other way. He did not expect the gas-turbine to displace the Diesel engine on the light pressure end of the expansion curve, but to supplement it by working on the portion of the expansion-curve for which a cylinder-piston did not seem suitable.

Mr. CHARLES ERITH wrote that no one would dispute the advisability of adopting internal-combustion engines using crude oil fuel in the tropics or in other places where coal fuel was extremely costly. For naval purposes, where cost was a secondary consideration, the many advantages of the crude-oil engine were undeniable, and in the mercantile marine there was also a wide scope. But for large electric power-stations, using low-priced fuels, whether coal, gas, or oil, steam was likely to be retained, as the internal-combustion engine was limited to reciprocating motion, whereas steam was adapted for turbo-generators of high rotative speed, with the most important advantages of low cost, weight and space, unlimited unit capacity, wide range of economical load, large overload capacity, great simplicity, and very low attendance and upkeep charges. These advantages entirely outweighed the inferior thermal efficiency of the steam-plant as compared with the internal-combustion plant. In California, where crude oil was cheaper than coal, such oil was burnt under boilers in order to obtain the many advantages of the steam turbo-generator for large electrical power plants.

In collieries here, producing coke for metallurgical purposes in by-product coking-ovens, the coke-oven gas was burnt under boilers supplying large-unit steam turbo-generators, even in cases where every facility existed for selling surplus power—as, for instance, in the plants connected with the Newcastle Electric Supply system, where the power generated from coke-oven gas in boilers supplying large-unit steam turbo-generators supplemented the power generated direct from coal burnt smokelessly on mechanical stokers in steam-boilers supplying similar steam turbo-generators of high rotative speed. The average cost of coal at large British electric power-stations was probably about 8*s*. per ton, and with highly efficient mechanical stokers it was perfectly practicable to generate 1,000 kw.-hours from a ton of such small coal in a modern steam-turbine plant. With any such cost for coal fuel, experience showed that the large-unit steam turbo-generator plant produced power to better advantage than any form of internal-combustion plant, the latter being restricted to reciprocating motion. In certain cases of exceptionally high load-factors and very little range of load, as in certain chemical industries, the direct utilization of bituminous coal in producer-gas plants with ammonia recovery could compete with the steam turbo-generator plant; but Dr. Diesel's forecast of the distillation of coal into coke and tar, for the purpose of generating electric power partly by using the coke in gas-producers for gas-engines, and partly by using the tar in crude-oil engines, did not appear at all likely to be realized on any large scale in this country. The production of tar-freed fuel, in the form of "Coalite" or partly-coked coal for both domestic and power use, had not been a commercial success, and Dr. Diesel's proposal appeared to be of a similar nature.

Apart from ship propulsion the scope of the crude-oil engine in this country, and in all other countries where coal was cheap, would appear to be limited, for commercial reasons, to small

(Mr. Charles Erith.)

powers. There did not appear any probability that any large British electric generating station could afford to forego the unlimited unit capacity, the wide range of economical load, the low cost, weight and space, and the simplicity and general convenience of the steam turbo-generator of high rotative speed. These very important advantages far outweighed the inferior heat utilization of the steam-plant in comparison with the internal-combustion engine.

Mr. P. T. HOUSTON wrote that Dr. Diesel stated (page 184) that 40 per cent. of the present production of mineral oil was sufficient to supply the whole of the naval and mercantile fleets of the world with power if worked by Diesel engines. If the naval fleets were left out of the question altogether, in 1911 there were about 37,000,000 tons of steam-shipping. The average power required per ton gross amounted to about 1 h.p., taking into consideration mail boats, fast cargo boats, tramps, excursion and cross-channel steamers. Taking the average consumption of a Diesel marine engine at 0·5 lb. per h.p-hour (for all purposes), he found that it required per annum 1·55 tons of oil fuel per h.p., so that the oil required for the merchant fleets alone amounted to 37,000,000 × 1·55 = 57,350,000 tons. This was more than the total output of mineral oil per annum according to Dr. Diesel's figures.

The quantity of 1·55 tons per h.p. per annum above mentioned, which was based on the running of modern cargo steamers with which the writer was connected, was arrived at as follows:—

Time on outward passage—21 to 22 days.
Time on homeward passage—21 to 22 days.
Time in port, 8 days abroad, 10 days at home—18 days.
Voyages per annum—5½ to 6.

Fuel oil required per h.p. per annum under way:—

$$\frac{1 \text{ h.p.} \times 0\cdot5 \text{ lb.} \times 24 \text{ hours} \times 44 \text{ days} \times 6 \text{ voyages}}{2{,}240} = 1\cdot41 \text{ tons.}$$

Fuel oil required in port, taking the auxiliary power as 25 per cent. of the main (main engines = 4,700 h.p.) and as shown by the "Selandia" and other vessels:—

$$\frac{0{\cdot}5 \text{ lb.} \times 24 \text{ hours} \times (4{,}700 \times 25) \times 18 \text{ days} \times 6 \text{ voyages}}{2{,}240} = 679{\cdot}8 \text{ tons.}$$

$$\text{Per h.p. per annum} = \frac{679{\cdot}8}{4{,}700} = 0{\cdot}14 \text{ ton.}$$

$$\text{Total} = 1{\cdot}41 + 0{\cdot}14 = 1{\cdot}55 \text{ tons.}$$

On page 184 the author stated that in the great development of tank vessels they were, or would be, mostly driven by Diesel engines. It was therefore strange to note that a very large Oil Company (see *Engineering*, 8th March 1912) showed that this was not so, as steam machinery was being fitted in a large new fleet of tank vessels which they were building.

It was stated (page 185) that the Diesel engine was having an influence with manufacturers of gas and coke. This might be so, but it must not be forgotten that the coke or coalite produced was a cheap fuel for gas-engines.

The author stated (page 205) that "Great Britain has the greatest interest in replacing the coal-wasting steam-engine by the more economical Diesel engine." Economies to the extent of 50 per cent. to 60 per cent. and over in coal-consumption could be had by using the coal in gas-producers and gas-engines. At the ordinary prices ruling for coal and petroleum fuel oils, the fuel cost of ordinary steam and Diesel engines was about the same in this country, so that the use of the gas-engine and gas-producer showed a net saving of 50 to 60 per cent. in fuel costs as against the Diesel engine. From this there did not appear to be much advantage in the use of Diesel engines. There was plenty of coal in the United Kingdom, and just lately there had been opened in Yorkshire an enormous coalfield, stated to contain thirty-five thousand million tons, which, if used in gas plants, would supply 100 million h.p. for 100 years, a quantity sufficient to run the steam tonnage of the world for nearly 300 years. There were still huge quantities of coal in Great Britain and Ireland quite untouched.

It might be argued by those in favour of Diesel engines for marine purposes that the marine gas-engine had not yet arrived, but this was not so. During the last five years a syndicate with which the writer was connected had been carrying out experiments with marine gas-engines and gas-plant. The results had been eminently

(Mr. P. T. Houston.)

satisfactory, the engine, which was a three-cylinder two-cycle double-acting and directly reversible one, doing all that a steam-engine could do, and doing it better, being much more rapid in manœuvring than either compound or triple steam marine-engines. This particular engine had frequently been timed from full ahead to full astern in 3 seconds, and had often carried out as many as twenty-seven different orders in 20 to 22 minutes, all this in the ordinary course of docking or undocking *and without loss of air-pressure.* Various grades of ordinary steam-coals had been used in the producers with excellent results. This engine would be heard of in the near future.

He would like to ask the author if there were any truth in the report that the Hamburg-American liner built by Blohm and Voss was now being fitted with steam-engines? The reason given was that the Diesel engines made for her had proved very unsatisfactory; moreover the vessel had already been delayed nearly twelve months waiting for the machinery. If this was so, it would be interesting to know the reasons, with which no doubt Dr. Diesel would be conversant. There was also a report that great difficulty had been found with the compressed-air starting-valves in the large Diesel engines, trouble being more particularly experienced with these valves after the engines had been running for some time and had been stopped and then restarted. Could any information be given on this point?

With regard to the vessels "Toiler" and "Vulcanus," a saving in fuel cost to the extent of 50 per cent. as against steam was claimed. This seemed to the writer to be quite an excessive figure, and it would be interesting to know the prices of the coal and the fuel-oil on which the statement was based. In the case of the "Toiler" more particularly, sailing from the Tyne, her bunker coal would not be more than 8*s.* or 9*s.* per ton. Taking the coal-consumption at 2 lb. per b.h.p. per hour, the consumption in 24 hours would be 7·7 tons, this at 9*s.* per ton = £3 9*s.* 3*d.* Taking the fuel-oil to cost 43*s.* per ton, the cost was £3 15*s.* 3*d.* per day, or 6*s.* per day in favour of the steam-engine. He thought the above figures were reasonable, and, on the small consumption of oil stated, it looked as though the engines were not working at anything like full power. It was common practice among sea-going engineers to push the boilers hard, get plenty of steam, open the engines out and take indicator cards. Then shut the engines in again. The horse-power was worked out from the cards, and the consumption per horse-power was worked out on the coal consumed perhaps over three or four weeks' running. The results were obviously wrong. He thought the same thing must apply to the results obtained from the " Toiler " ; and very similar remarks applied to the " Vulcanus."

Dr. Diesel and others had pointed out that the Diesel engine could not be built cheaply, which meant that the finest materials and the finest workmanship were absolutely essential. Consequently, practically no firms of ship and engine repairers would be capable of making good any damage sustained by the engines. This would prove an exceedingly awkward matter for all concerned, but more especially for the underwriters who insured the vessel, as there would be no competition amongst firms for the repairs, and high prices would in consequence be the rule. It was also possible that the vessel would have to be towed long distances to a firm who could do the repairs, all adding largely to the cost, and eventually increasing the premium on the machinery insurance. He wrote from experience of marine engine and ship repairers, and could confidently state that 99 per cent. had neither the tools, men, nor experience that would enable them satisfactorily to repair Diesel engines.

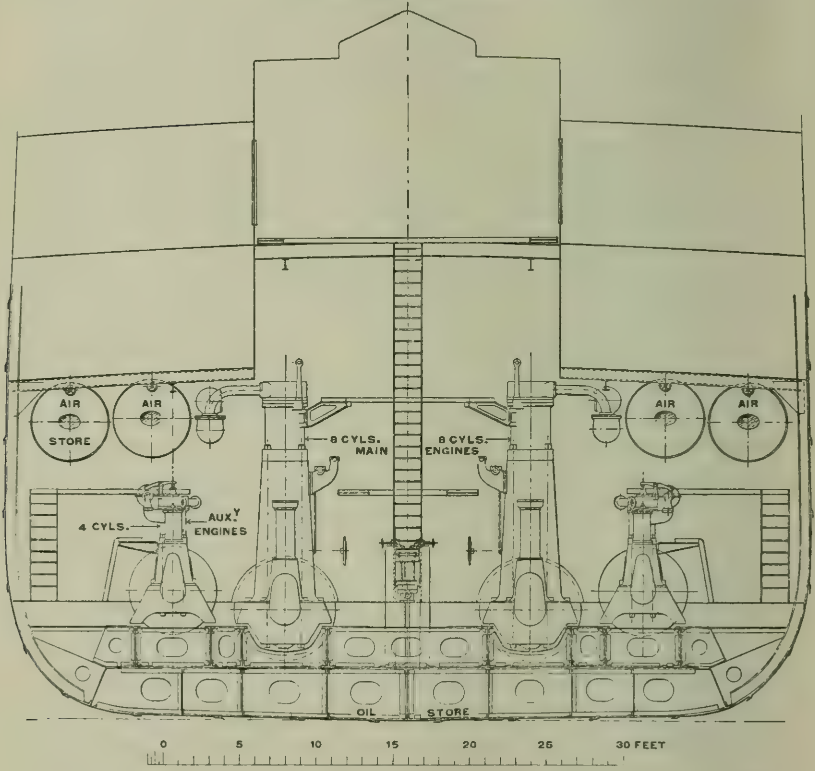
A serious point in connection with the fitting of Diesel engines to ships was the fact that the fuel was practically mineral fuel-oil only. The mineral oil industry was in the hands of only a few companies, who apparently worked together and controlled the prices. Within the last few months the price of fuel-oil had been raised from 43*s*. to 90*s*. per ton for no apparent reason. The coal strike at present in this country was not the reason for so doing. At 90*s*. per ton the fuel cost was at least double that which it would be with coal and steam, and one had no guarantee that the same treatment would not be dealt out in the future.

Mr. John W. Wainwright wrote that in the Paper a number of Diesel-engine ships were mentioned, built by Russian, French, and German Companies, which were stated to be of large horsepower, but little was published regarding these boats. Moreover, in some cases the ships, as mentioned by Dr. Diesel, were, even if built, at least not yet working with Diesel engines. Whereas the Danish motor-ship "Selandia" (*see* cross section shown in Fig. 35), the largest sea-going motor-ship afloat, now on actual service,

Fig. 35.

Cross Section through Engine Room of Motor-Ship "Selandia."

2,500 h.p. of Main Engines direct coupled to Twin Screw (four blades), 7,400 tons dead weight.



designed, built and engined by Messrs. Burmeister and Wain, of Copenhagen, although not referred to by name in the Paper, was launched in November 1911 and was in London at the end of February. The "Selandia" reached Genoa after a most successful voyage, and in the rough passage through the Bay of Biscay the engines acted splendidly and were well controlled by the Aspinall governors. In the tortuous passages leading from the West India Docks the pilots found everything most satisfactory, although as many as eighty different manœuvres on each engine were made in coming out of the docks into the river. This large number of manœuvres in so short a time was only possible by the special arrangement for the supply of compressed air for starting and manœuvring.

The "Selandia" was 370 feet long between perpendiculars, 53 feet beam and 30 feet in moulded depth to upper deck. She had a speed with full cargo of 12 knots. The sister ship "Fionia" was now launched at Copenhagen, and Messrs. Barclay, Curle and Co., of Glasgow, had practically completed another—the "Jutlandia." The writer gave some particulars below, most of which had been furnished by Mr. O. E. Jörgensen, chief engineer of Burmeister and Wain:—

The main engines of these three boats are each of the four-cycle, vertical, single-acting type with outside cross-head and with enclosed crank-chambers and forced lubrication. They are of 1,250 i.h.p. each, with eight cylinders per engine. Speed 130 revolutions per minute at sea. These gave 1,700 i.h.p. on the test bed. The air for manœuvring and starting was furnished by an auxiliary Diesel engine of 200 b.h.p. directly connected to a three-stage air-compressor of 20 atmospheres pressure. When the engines were running in actual service at sea, this compressor acted as the low stage of injection air for the main engines, the later stages being obtained by the high-stage compressor directly connected to the main engines. By this arrangement an adequate supply of starting air was always available, and part of the power of the auxiliary engine was always utilized.

The mechanical efficiency of the main engines was 85 per cent., but as 70 h.p. was supplied by the low-stage compressor, the actual

(Mr. John W. Wainwright.)

mechanical efficiency would be about 80 per cent. The engines had proved most economical in oil-consumption (about 9·8 tons of oil per 24 hours run with 2,500 i.h.p. including auxiliaries), and the combustion was perfect. The reversing control had never given the slightest trouble and was quick in action. The propellers with the ship at full speed could be reversed in 20 seconds. This design of four-cycle engine had proved absolutely reliable in action and safe in use.

In the Paper the two-cycle system was strongly advocated by Dr. Diesel, but it was doubtful if this were correct; for economy in fuel was the most important saving that was effected by the employment of Diesel engines on board ships. Very little space of a useful nature was saved by using two-cycle engines under existing rules. As to *guaranteed* fuel-consumption in the case of large engines, in public tenders these were usually given as 0·180 to 0·185 kg. per b.h.p.-hour (0·396 to 0·407 lb.) for four-cycle type, but for two-cycle engines these were given as 0·225 to 0·230 kg. per b.h.p.-hour (0·495 to 0·506 lb. per b.h.p.-hour). This was equivalent to about 25 per cent. greater fuel-consumption for the two-cycle type as compared with that of four-cycle engine. Taking for example a ship of the same size as the "Selandia," running from England to South America, in which case sufficient fuel had to be carried for the double voyage, by installing Diesel instead of steam-engines, the saving would be the difference between the cost of 2,000 tons of coal and 500 tons of oil, when using the four-cycle engine. Further, a larger amount of cargo could be carried. If engines of the two-cycle system were used, the quantity of oil would have to be increased by 125 tons, which at present prices meant about £300 more per round trip. To counterbalance this large additional fuel-weight, the saving in engine weight would have to be very considerable in the case of the two-cycle system. As this saving in weight was about 15 per cent. in the main engines, whilst the auxiliaries, the shafts, propellers, silencers, pipes, etc., were exactly the same in both cases, the total saving would be only 7·5 per cent. in total machinery, or about 35 tons in a ship of the size of the "Selandia." With regard to weight, taking all things into consideration, it was beyond question that this was more favourable in the case of the four-cycle than in that of the two-cycle engine, when used for ships.

The main advantage of the four-cycle over the two-cycle type of engine was, that its working process was simpler, and, as Dr. Diesel had said in his Paper, the combustion, a most important figure in the Diesel engine, was more clean and complete, and therefore the safe working was more ideally obtained by the former cycle. The safe working of the engine was even more important than the question of economy; it also reduced insurance charges, besides giving better freights and commercial success to the ship. In the case of the "Selandia" the bulk of fuel-oil was carried in the double bottom, and in quantity sufficient for the round trip from Siam to Denmark. The oil-fired donkey boiler was installed to supply steam for heating purposes and for running a stand-by compressor. The winches were all electrically driven by current obtained from the main electric generator direct-coupled to an auxiliary Diesel engine. The steering gear was controlled by the Martineau and Hele-Shaw hydraulic system; and wireless telegraphic apparatus was installed.*

Mr. R. J. N. WILLCOX wrote that the machinery of the "Selandia" did undoubtedly demonstrate that up to a certain horse-power these engines could be successfully used on board ship to drive the ship. The number of cylinders assembled over one crankshaft would appear for practical reasons to be limited to eight. The great length of the crankshaft in the engines of the "Selandia" was a most prominent feature of the design. In the enclosed type engine, as in the "Selandia," the framing contributed greatly to maintaining rigidity in the long sole-plate. Where the open marine design of engine was used, the rigidity of the sole-plate largely depended upon that of the engine seating. In any ship there would be appreciable flexure in so great a proportion of its

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* Since writing the foregoing the "Selandia" has now completed her first voyage successfully, arriving at Bangkok on 21st April 1912, everything working satisfactorily.

(Mr. R. J. N. Willcox.)

length when pitching and rolling in a heavy sea. The stresses on the cranks necessitated bearings at each side of each crank, so that the shaft could not be permitted any flexibility, and must in fact be firmly supported for its full length. These excessively long crankshafts, so firmly bound for their entire length, would in severe weather be subjected to incalculable strains; and trouble with the bearings, etc., seemed highly probable. Should the number of cylinders be increased beyond eight these difficulties would be increased. It would, on the other hand, seem desirable to reduce the number of cylinders and the length of the crankshaft. The power to be developed in each cylinder must therefore be from one-eighth to one-sixth of the whole.

In the four-cycle engine it was improbable that more than 200 to 250 h.p. could be got out of one cylinder unless the piston were cooled by water or oil circulation. It would probably be considered that 22 inches (perhaps as much as 24 inches) diameter was the limit for an uncooled piston. This was due to the fact that when cast-iron was subjected to continual heating to a high temperature, the metal expanded permanently and continuously. (To those unfamiliar with internal-combustion engine practice, the writer would refer to the well-known effect of superheated steam on cast-iron valve fittings.) Even with pistons only 20 inches diameter it would be found that it became necessary to turn down the piston for a portion of its length from the back end from time to time. For a single unit of anything above 1,500 to 1,600 h.p. it became necessary to adopt water or oil-cooled pistons if the piston speed was not to be abnormal. He assumed that, with an engine-room temperature of from 115° to 120° F. in hot climates, any suggestion of cooling by air-blast was out of the question, quite apart from the expense such method would entail.

The circulation of water or oil through the piston necessitated the use of telescopic or articulated pipes. The use of oil for circulating arose from the very great difficulty experienced in land practice in preventing leakage of water through the glands and joints of these pipes. A marine engine would be called upon to work satisfactorily under conditions never experienced on land or under trial trips. In a tramp ship running light, in a gale, no governor would ever eliminate the racing of the engines. Under such conditions telescopic pipes would soon be destroyed by the shocks due to the inertia of the liquid contained in the pipe system. A set of sixteen articulated pipes flying about an engine would not appear to be a very satisfactory solution of the difficulty, quite apart from the leakage which would quickly develop about the joints. The diameter of the piston could of course be kept down by resorting to the double-acting engine with its troublesome stuffing-boxes and complicated valve-gears, and also by the two-cycle engine. But in the larger units it again became necessary to cool the pistons. The difficulties anticipated with excessively long crankshafts and in cooling the pistons were, he believed, the most serious that constructors of large internal-combustion engines for marine work would meet. In limiting the power of this ship so that the dimensions of the engines had permitted them to avoid these difficulties, the owners of the "Selandia" had ensured immediate and complete success with their venture. But the step from engines of the size of those in this vessel to engines of double the power was out of the ordinary track into rough country.

The advent of ships using fuel which consisted wholly of crude oil introduced new risks to the property of the owners of docks where these ships traded. These were :—(1) The risk of explosion or fire on board of the ship carrying the crude oil; (2) The risk of damage by fire to other ships and to the warehouses and goods stored therein; and (3) The risk of a conflagration arising from the presence of oil floating over the surface of the water in a crowded dock. The presence of this oil might be due to its being pumped overboard with bilge-water or due to leakage from the oil-ship arising from defect in construction or from accident such as collision.

From repeated observation of the use of crude oil for internal-combustion engines on board ship and from the statements of those who were strong advocates of these engines, he believed it was very generally held that there was no danger of fire or explosion

(Mr. R. J. N. Willcox.)

connected with it. In every set of oil-engines he had yet seen there had been a leakage of oil about the engine, sometimes small in quantity but always appreciable. These drippings generally found their way into the bilges.

From practically every class of crude oil and at all temperatures (and increasing in quantity with the temperature) an inflammable vapour was constantly being given off. This vapour was much heavier than air, and therefore it gravitated to the bottom of a deep enclosed space such as an engine-room. The space beneath the starting platform, the bilges, etc., would in course of time become filled, because in these parts there was little or no circulation of air even when the number and size of the ordinary cowl down-draft ventilators was liberally provided. When at sea this system of ventilation might possibly, but not probably, be adequate. But when a ship was in a dock surrounded by high warehouses, cowl ventilators were of little effect, so that under such conditions the engine-room of a crude-oil-engined ship presented all the requisites for an explosion and general conflagration. In these ships in which the double bottom beneath the engine-room was used as a fuel tank the vibration of the engines must very soon lead to leakage at the holding-down bolts, the seams and rivets. Any accumulation of vapour in these tanks, arising from the free surface of the oil, and increased by the washing about of the oil when at sea, would pass out into the space below the platform and into the bilges. There would be a further contribution to the oil leakage above referred to.

In all oil-engines except the Diesel, but including the so-called semi-Diesel, the use of blow lamps was necessary, and in all large installations of Diesel engines electrically-driven auxiliaries or generators would be included. The blow-lamp, an electric spark, or a naked light were all capable of exploding an accumulation of inflammable gas, and since the use of none of them could, for practical reasons, be prohibited, it would appear that the possibility of such accumulation must be positively eliminated under all circumstances, not only in large ships but also in barges, tugs, etc. He was aware that in large installations the air contained in an engine-room might be consumed by the engine several times in the course of an hour, but, as the intakes were high up, this automatic ventilation did not affect the dangerous places in the engine-room, and of course in dock it did not take place. It therefore seemed highly probable that the owners of the docks would be called upon to protect their own interests and those of their customers by insisting upon—(1) The provision when in dock of mechanically-operated exhaust-ventilation in the engine-rooms of all ships using crude oil; (2) The isolation of steam-boilers, oil and coal-fired, from the engine-room; (3) The prohibition of the use of the double bottom beneath the engine-room for the storage of crude oil. An accident arising from the cause indicated would very seriously retard the progress of the internal-combustion engine. The liability to such an accident did undoubtedly exist, and yet did not appear to be fully appreciated by many of the strongest advocates of the use of crude oil, but the elimination of the liability could be effected at very small first and subsequent cost.

Mr. J. VEITCH WILSON wrote that he had hoped the author would deal with the much discussed question of lubrication in connection with the Diesel engine. This was, however, obviously impossible on account of the volume of historical, technical and statistical information which he had given in the Paper. The question was, however, so vitally important to all users of these engines, that he ventured to offer some remarks on the subject.

All internal-combustion engineers were aware of the fact that, while few troubles were encountered in the lubrication of engines using town-gas as fuel, the difficulties in connection with other types rose in progressive gradients through engines using suction-gas, petroleum spirit, and light and heavy oils. Our present experience seemed to indicate that, while, in some of the simpler forms of engine, hydrocarbon oils might provide the necessary lubrication, such oils were unsuitable when the difficulties of lubrication increased with the heavier grades of fuel. Under these latter circumstances it had been found that, for oil engines generally, compound oils, that is, hydrocarbon oils with various percentages of fatty oil, and, in the case of two or three engines, pure vegetable oils were required to

(Mr. J. Veitch Wilson.)

secure successful lubrication and moderately clean cylinders. It might be invidious to cite particular engines, but members would probably be able to recall those in which mixtures containing from 10 to 50 per cent. of vegetable oil were satisfactory, and others in which pure or nearly pure vegetable oils, such as castor or olive, were required.

He had indicated above that the advantages which these compound oils offered, as compared with hydrocarbon oils, consisted not only in their superior lubricating properties, but in the somewhat remarkable fact that they appeared to prevent deposit and to promote the removal of such deposits as might be formed. The earlier internal-combustion engineers held very strongly that, because the lubricants were to be subjected to high temperature, only hydrocarbon oils might be used. They believed that mineral oils would be carried away without deposit, while vegetable oils would liberate fatty acids and produce gummy and carbonaceous deposits. As far as the liberation of fatty acids was concerned, the fear was not warranted as, for the production of such acids a liberal supply of oxygen was required, and it was the purpose of the designer of internal-combustion engines to arrange that the supply of air should introduce the exact amount of oxygen required for combustion. In the absence of superfluous air and oxygen there could be no acidification. As regards gumminess, this also resulted from the absorption by the oil of oxygen, and as he had shown in the preceding paragraph that in a well-designed engine there was no excess of oxygen, gum could not be produced.

Carbonization arose from excess of unconsumed carbon, but surely a pure hydrocarbon oil—84 per cent. of carbon plus 16 per cent. of hydrogen—was more likely to produce carbon than a vegetable oil which contained in addition to carbon and hydrogen 10 to 15 per cent. of oxygen, which was sufficient to provide for its smokeless combustion in an open lamp under circumstances in which pure hydrocarbon oils would give off dense volumes of smoke. It followed, therefore, that the oil which gave off smoke in this liberal fashion was more likely to produce carbonaceous deposits in the cylinders than the oils which might be burned without smoke.

In the writer's experience of Diesel engines he had found that satisfactory results in respect to lubrication were obtained by the use of compound oils, and he was in the habit of recommending these. He found, however, to his regret, that many owners of Diesel engines, probably because they found it possible to use cheap semi-refined oils for fuel, argued that cheap oils ought to be sufficient for lubrication. Steam engineers took a different view of the subject, and although their power element, steam, might promote lubrication by condensation in the cylinder, were careful to select good lubricating oils, even although the prices might be relatively high. He considered that as the Diesel engine was undoubtedly adapted to work lower grades of fuel than the majority of oil-engines and might probably show more tendency to produce deposits in the cylinder, it must call for higher grades of lubricating oil, and it would be interesting to have Dr. Diesel's opinion upon the subject.

Dr. **Diesel** wrote, in reply to Mr. Churchill-Shann, that he was unable to form a sufficiently clear idea of the proposed compound engine from the description, which was not accompanied by drawings. In reply to the question whether he (Dr. Diesel) had made any experiments in this direction, immediately after the first successes with his single-cylinder engine in the years 1897–98 in the workshops of the Maschinenfabrik Augsburg, he had built a large 150 h.p. compound engine, in which the compression of the air for combustion as well as the expansion of the combustion gases took place in two stages. Experiments which were carefully carried out for more than a year showed that the heat and pressure losses of the hot gases in their passage from the high-pressure to the low-pressure cylinder were quite enormous, so that the heat economy was lower than in the gas-engines of that time. In spite of the large expenditure in money and time, he was obliged to come to the conclusion that this system was useless. A description of this engine and the experiments made was published at the time in some German technical journals.

(Dr. Diesel.)

Mr. Charles Erith defended the steam-turbine for electrical central stations against the Diesel engine. He (Dr. Diesel) would like to take this opportunity to state that he had never expressed anywhere the opinion that the Diesel engine would replace the steam-engine in all its forms and applications. He had been content to compare in a scientific manner the thermodynamic results of one with the other, and left it to practice to draw conclusions therefrom. It was obvious that the steam-engine was still supreme in many cases in spite of its thermodynamic inferiority. It was a simple question of calculation in each case, where the prices of solid and liquid fuels must first be compared; also the personal costs, and subsequent application of the exhaust for heating purposes, etc., must be considered. Other points must be kept in view, such as the requisite space, convenience, hygiene, etc., which could not be directly expressed in figures. The fact that about 60 per cent. of all Diesel engine plants had been erected in central electric stations proved that the steam-engine was not the engine for those stations in *all* cases. The Diesel engine had not the same opportunity of being installed in *large* central stations as had the steam-engine. The latter, on account of its special qualities, worked economically in large central stations only. The Diesel engine, on the other hand, was as economical in small as in large stations; and as it could be installed everywhere without secondary plant was always ready for working without any preparation, and as it required little space it was the predestined engine for decentralization. In many cases, instead of using a large central steam-engine station, it had been shown to be correct to lay out a number of smaller central stations, distributed in various places, with Diesel engines, and to avoid thereby the material and other losses due to wide electric-power transmission. This question was in each particular case a matter of calculation.

Mr. P. T. Houston thought that the author's calculations for the consumption of oil by naval and mercantile vessels were incorrect. The calculations did not originate with him, but from Professor Laas of Charlottenburg, and were published in the well-known paper, *Petroleum*, of 3rd June 1911. He accepted these after obtaining, in correspondence with Professor Laas, sufficient information and further data, as follows: The indicated horse-power contained in the whole mercantile shipping of the world had been calculated at 22,000,000, and the whole naval shipping at 15,000,000. From various accounts of large and small shipowners, as well as from accounts of coal consumption in naval shipping, it was found that about 50 per cent. of this horse-power with mercantile steamers and 5 per cent. with naval ships, was full work during the whole of the year. If one took the oil consumption of Diesel engines at 160 grammes per i.h.p., a figure which was generally easily attained by large and small engines, it was found that the whole consumption for 365 days of 24 hours was 16,000,000 tons, or, as he had said in the Paper, 40 per cent. of the whole present world production of petroleum of 40,000,000 tons. One could thus get an idea of what the Diesel engine question signified in reference to the present world production of petroleum. It followed also that the foundations of Mr. Houston's calculation for petroleum consumption were inadmissible.

As regards tank-ships for petroleum transport, he had mentioned that *most* of these ought to be provided with Diesel engines; he did not say *all*. He knew well that some of these ships were still provided with steam-engines, because many shipowners still awaited further experience with Diesel-engined ships, and because with the present very rapid increase of tank-ships the demand for Diesel engines for their working could not be satisfied.

Mr. Houston also defended the gas-engine against the Diesel engine. In reply to him the author must emphasize that it had never entered his mind to attack the gas-engine. He repeated over and over again that one ought to convert solid fuel, such as coal, into gas, in order to make it of value in the economical gas-engine, while liquid fuels were reserved for the Diesel engine; thus gas-engines and Diesel engines went completely on parallel lines and near to each other, and were in no way competitors. Under all circumstances, however, both were far superior thermodynamically to the steam-engine.

(Dr. Diesel.)

With regard to his remarks about the savings in the ships "Toiler" and "Vulcanus," he had taken these from English journals; the data upon which these calculations were made were also to be found there. He quite agreed with Mr. Houston that all calculations *in advance* about the saving in engine working were only to be accepted with caution, and that only the practical results which were obtained in the course of years, could be decisive. It was, however, obvious that shipowners, for their own satisfaction, made such calculations beforehand, and that these were of interest to the larger public. Finally, Mr. Houston feared the difficulty of repairing Diesel engines, because of the fineness of the work required in doing so. The Diesel engine required good workmanship and materials as a guarantee of work and durability. A Diesel engine must always be a finely built engine, and it would thus require fewer repairs than engines which were of inferior construction. If duplicates of some of the most important parts, which required special materials, were carried on board ship, the risk was not so great. It was, however, also obvious that with the general introduction of Diesel engines in shipbuilding, the engine workshops concerned would be obliged to conform to the new requirements. Such a process of adaptation was required by every improvement and came naturally.

In reply to Mr. John W. Wainwright, it was true that the "Selandia" had not been mentioned in the Paper, the reason being that the preparation of such a Paper took several months, so that it was already in print before the great success of the "Selandia" was known. He had, however, at the Meeting shown a lantern slide of this vessel, and had also referred to the great success of this ship, which had been known only a few weeks before the reading of the Paper. He was one of the admirers of this ship and had the greatest respect for the firm of Burmeister and Wain.

Mr. Wainwright also reopened the question of the four-cycle and two-cycle engine. This had now been dealt with so much that one ought to wait now for the results of experience. The reason why the two-cycle system was preferred in all more recent experiments for building larger ship engines was that the combustion cylinder became smaller. It was known that the difficulties of this engine increased rapidly with the size of the combustion cylinder, as Mr. Dugald Clerk rightly brought forward in the discussion. Manufacturers were greatly interested in the lessening of these difficulties, and the only means for doing this was the adoption of the two-cycle arrangement, either single-acting or double-acting. The general tendency was therefore towards the two-cycle system. But this did not in any way detract from the performances of the four-cycle, which were absolutely reliable, for the simple reason that they did not differ in anything (except the reversing) from the well-known old four-cycle stationary engine, and did not contain any new device which would have to be experimented with Compared with this predominant necessity for diminishing the dimensions of the cylinders, and in connection therewith also the dimensions of the shafts, the other questions of weight and space were of secondary importance, as were those of higher consumption of oil and of greater quantities of oil to be taken in the bunkers. The great simplicity of the valve-gearing and reversing also played a great part in the choice of the two-cycle system.

Mr. R. J. N. Willcox also discussed the two-cycle and four-cycle systems, and came in reality to the same conclusions as he (the author) had put forward. With regard to Mr. Willcox's fears of the danger which the presence of petroleum on the ships would cause in harbours, he could only refer to the numerous tank-ships which at present travelled over the seas, as well as to the numerous warships which used petroleum, either exclusively or with coal, for their boilers. To his knowledge very few mishaps had occurred which might be attributed to these liquid fuels. The administration of the American Marine seemed to share this view as well, for they had only this year decided gradually to install heating by petroleum throughout their navy; and the companies which controlled shipbuilding, such as Lloyd's Register of British and Foreign Shipping, Bureau Veritas, etc., did not seem to have any fears in this respect. Of course all precautionary measures, which Mr. Willcox mentioned, against these dangers, must have careful attention, and the insurance companies had also made rules providing for these.

(Dr. Diesel.)

The remarks of Mr. J. Veitch Wilson (page 273) upon the natural qualifications of vegetable oils for lubrication were very interesting. Unfortunately vegetable oils seemed so liable to form acids when they became warm, that great precaution was required in their application for lubrication purposes. This formation of acids did not only originate, as Mr. Wilson thought, from the oxygen of the surrounding air, but from the strong contents of chemically-bound oxygen in the vegetable oil itself, so that acid was also formed when the oil was warmed in closed vessels At any rate, up to now only pure mineral oil of the best quality had been used for lubricating all the engine-parts in Diesel engine practice, and he would not like to advise anyone to depart from this without the very best reason.

THE DIESEL OIL-ENGINE.*

BY HERBERT S. PURSEY, *Associate Member*, OF CALCUTTA.

[*Selected and abridged for Publication.*]

The first few pages of the Paper consist of a description of the Diesel engine. The author then proceeds to discuss its advantages and disadvantages, as follows:—

Advantages and Disadvantages.—In the first place, it is to be regretted that there is not more difference between the capital cost of a Diesel engine and a modern steam-plant, having regard to the fact that a steam installation has to provide boilers, chimney, etc., but doubtless this will adjust itself. Even now the newest types—both high-speed and two-stroke—though not quite so efficient as the type described, are considerably cheaper, the difference in price of a 1,000-h.p. engine being as much as 25 to 30 per cent. However, where land is valuable, the small space required, as compared with steam, together with the saving in the buildings, is a large item, for in the marine type the saving in space is between 30 to 50 per cent., while the weight is 50 per cent. less.

Regarding the working expenses, the chief savings and advantages are:—

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* This Paper was read and discussed at a Meeting of the Calcutta and District Section on 24th January 1912. It is illustrated by 2 Plates and 3 Figs. in the letterpress, and a copy may be seen in the Library of the Institution.

(1) The absence of any stand-by charges, and the rapidity with which the engine can be put on load.
(2) The far greater thermodynamic efficiency.
(3) The minimum of labour required in dealing with the fuel, and the smaller engine-room staff.
(4) The lower cost of repairs.
(5) The small amount of water required.

Dealing with the first item and assuming the engine to be left exactly as shut down, the order of procedure in starting up is as follows:—

(*a*) See all lubricators are in working order and fuel-pipes flooded.
(*b*) Pull over hand-lever to place starting-valve in working position.
(*c*) Bar engine round to just over dead-centre on starting cam.
(*d*) Open out screw-down valves on blast.
(*e*) Open out storage-bottle for the first three or four revolutions, and then adjust hand-lever to disconnect starting-valve.

This can all be done quite easily by one man and in a very short space of time; the author has by himself started up engines of 300 b.h.p. and been on full load in 1 minute. Thus it will be understood there are absolutely no stand-by charges, and where, as in cases of emergency, the time required in starting is of the greatest importance, the Diesel engine has a great advantage.

2nd item.—The over-all thermodynamic efficiency of a steam-engine, condenser and alternator working under the best conditions, cannot with safety be placed above 12 per cent., but that of a Diesel engine burning crude petroleum at about 18,500 B.Th.U. is at least 31 per cent., and remains nearly constant for all sizes of units. This is made up roughly as follows:—

	Per cent.
Calorific value of fuel	100
Loss in exhaust, cooling, etc.	55
Indicated horse-power	45
Loss in engine-friction, air-pump, etc.	11
Brake horse-power	34
Generator loss @ 91 per cent.	3
Efficiency	31

The latter item of course varies slightly according to the load, but it may be taken roughly as follows:—

Full load.	Three-quarter load.	Quarter load.
31 per cent.	29 per cent.	25 per cent.

The author's experience unfortunately does not extend to the latest improvements which have been made, and which have considerably advanced the efficiency. Messrs. Sulzer Brothers have constructed a special waste-gas utilizer which, if the 25 to 30 per cent. lost in cooling water is taken advantage of, will bring the efficiency as high as 80 per cent. The ratio of b.h.p. to i.h.p. (70 per cent.) appears very low as compared with a steam-engine, but this is no great disadvantage, and is not due to mechanical design. The difference is owing to the air-compressor, which however is preparing the crude oil into its most suitable form for combustion by atomizing, heating and igniting it. Therefore, in order to obtain a fair comparison with steam, all the power used in the boiler-house on mechanical stokers, economizers, fans, etc., which are doing precisely the same work, ought to be taken into account.

The pounds of oil per b.h.p., at about 18,500 B.Th.U. per lb. at the different loads, are approximately:—

Full load	0·44 lb.	per b.h.p.	per hour	oil @	Rs.40 per ton	=	0·12*d*.
¾ ,,	0·45	,,	,,	,,	,,		0·13*d*.
½ ,,	0·51	,,	,,	,,	,,		0·14*d*.
¼ ,,	0·71	,,	,,	,,	,,		0· 2*d*.

It should be borne in mind that it is never necessary to run an engine on ¼ load, for on a three- or four-cylinder set, one or two cylinders can be cut out quite simply at the oil-distribution boxes, and this without upsetting the balance of the engine to any appreciable extent.

Numerous instances could be quoted where large savings have followed the adoption of Diesel engines. At Rhyl, where a Diesel engine is running in parallel with steam plant, the generating costs have been reduced from 1·3*d*. per unit to 0·79*d*., a saving which, though 40 per cent., would be still greater with Diesel engines alone. At Lewes a 200-b.h.p. set is recorded as having effected a saving of 75 per cent. in the works costs as compared with steam.

The following figures * are the averages of official records from almost all the electric stations in Great Britain, having a plant capacity of 1,000 h.p. or less:—

Cost per B.T.U. sold.

Type of Engine.	Load Factor.	Fuel.	Lubricating oil stores, water, etc.	Wages.	Repairs and Maintenance.	Total.
						d.
Steam .	14·7	0·45	0·06	0·25	0·26	1·02
Gas . .	15·3	0·43	0·09	0·28	0·24	1·04
Diesel . .	14·3	0·23	0·04	0·19	0·07	0·53

3rd item.—All boiler-house staff is done away with, and there is practically no labour required for handling the fuel.

4th item.—The low cost of repairs, if the engines are properly looked after, is fully borne out by most engineers who have been in charge of Diesel plant. At Leatherhead, Surrey, for the first three years the cost repairs on two engines of 120 b.h.p. each is given as under 40*s.*, while the man who looked after them while they were running was an ex-stoker with no special engineering training. Owing to the perfect combustion, there is practically no deposit on the top of the piston, though this of course to a great extent depends upon the nature of the fuel consumed; generally speaking it is only necessary to draw the pistons for examination about once a year. This is to overhaul the rings and little end.

It is most important that indicator cards, which are obtained in precisely the same way as with a steam-engine, should be frequently taken in order that the best results may be obtained. Often a very small adjustment of the fuel-valve will make a vast difference in the combustion. In the ordinary way, when the suction and exhaust valves have been correctly set, they will need no alteration in lead for long periods.

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* *Paper* by Charles Day. Transactions (Section G), British Association, 1911, page 487.

It is desirable that the compression in the cylinder should remain constant at 32 atmospheres, and to obtain this the exhaust-valves which are liable to soot up should be taken out, cleaned and ground to their seatings whenever necessary. The length of time between each cleaning of course depends on the quality of the fuel consumed, but with Borneo oil as supplied in Calcutta, it is only required about once a month. Explosion cards, which are obtained by turning the indicator by hand during the working stroke, are extremely useful, and show at a glance if the oil is being admitted at the correct moment, and if the period of admission is properly regulated. That Diesel engines can be relied upon for long continuous running is proved by the statement that a 150-b.h.p. set ran continuously at the Birkdale Electricity Works for four weeks, and 8,447 hours out of a possible 8,760 during the year 1909.

5th item.—Roughly 5 gallons of water are required for the cooling jacket per b.h.p.-hour with a rise of temperature from 90° to 115° F.; if a cooling tower is used, the total amount required is therefore very small, an important point where water is scarce or bad.

The disadvantages of the Diesel engine itself compared with steam are few. In fact they are practically nil, with the exception of overload; Diesel engines will not stand more than 15 per cent. to 20 per cent. (after which the set will miss-fire owing to the low compression). The most serious drawback is the price of oil, which is subject to extreme fluctuations, having varied in England during the last few years from 42*s.* to 75*s.* per ton. In India, however, the price seems to be remarkable for its consistency in gradually creeping up. Apart from this, oil may be obtained in future from coal lignite, peat, shale, etc., in sufficient quantities to compete with mineral oil, and thus steady the market price. If bituminous coal is distilled at a low temperature, it will give approximately

70 gallons to the ton, or roughly 1 in 4. In a country like England, however, with good cheap coal, and as at present only a limited supply of oil, it must be admitted that under ordinary circumstances the Diesel engine only competes with steam in the smaller units, but still where coal is indifferent and where there is a good supply of oil-fuel obtainable, there ought to be a big future before it. It is interesting, however, to note that the Charing Cross and Strand Electricity Co., London, have not further extended their 3-phase system, but have installed Diesel engines instead, and have stations of 1,000-kw. and 3,600-kw. now running quite satisfactorily at Cannon Street and Drury Lane respectively. Doubtless this is partly due to the heavy cost of cable laying in London, and to the rapidity with which Diesel engines can be put on load, which in the case of a London fog is a most important factor.

Marine Engines.—Even at present some of the Dreadnought class of battleships and cruisers have been fitted with Diesel engines for the auxiliary work, which is not a small item, but large boats (5,000 tons) are being built, or have been just completed, with main engines of this type. The small space required both for engines and fuel storage, the small amount of labour necessary, while in tropical seas, a cool engine-room and no boilers are a combination of advantages almost too great for the sea-going engineer to realize. Safety is another consideration, for with the high flash-point of oil, risk of any explosion is practically nil. The weight is another point of great consequence, for although the Diesel engine is heavier, it is proportionately lighter when the boilers, condensing plant, etc., of the steam-engine are taken into consideration.

Two-cycle engines are now being made for marine work. The principle is exactly the same except that the compression strokes are done away with, and the oil exploded by a charge of compressed and heated air introduced from outside just before the end of the exhaust stroke, the exhaust gases having been previously cleared from the cylinder by a scavenging blast at about 3 to 5 lb. per square inch. The chief advantage of the two-stroke engine is that the exhaust valves are done away with, their place being taken by ports in the cylinder which are uncovered by the piston at the end of the stroke. Reversing is obtained by an extremely simple arrangement on the cam-shaft.

Double-acting engines are also now being built, and are commercially successful, as the stuffing-box problem—a very difficult one in face of the high pressures and temperatures—has been satisfactorily solved. It is unfortunate that in the large sizes the pistons should have to be water-cooled, as it adds complications to the engine. In most cases a telescopic arrangement is provided, but this in turn needs a stuffing-box to prevent the water mixing with the lubricating oil, which is filtered and used over and over again by the forced lubrication pumps. Mr. J. F. Schubeler, the author of the recent Paper * read before the Parent Institution, describes a very simple system by which the water does not fill the cooling space of the piston, but is only squirted against the highly heated surfaces, and drained off through a pipe which surrounds the spray-pipe. By this arrangement all additional pressures and strains are eliminated. In the larger sets of 1,000 h.p. and over, the air-compressor is usually separately driven by a small Diesel engine which allows the engines to be more easily handled.

Report of Test on 240 *b.h.p. Set under the Author's Supervision.*

Load.	Full Load.	Half Load.	Light Load.
Duration . . . mins.	30	30	30
Revolutions	177	178	180
Injection pressure (atmospheres) .	57	52	42
Units generated	74	36·5	15·4
Fuel consumed . . . lb.	52·5	32·5	20
Fuel per unit . . . „	0·709	0·89	1·29
Fuel per b.h.p.-hour . . „	0·47	0·6	0·86
Jacket-water pump-inlet . °F.	90	92	93
Jacket-water pump-outlet . „	120	115	110
Rise . . . . . . „	30	23	17
Gallons per hour. . . .	910	840	650

NOTE.—This test was taken after the engine had been running 3½ years with practically no repairs.

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* Proceedings, I.Mech.E., 1911, Part 3, page 579.

Table showing Costs at various Diesel Engine Stations.

Names of Plants.	Leatherhead. *	Coventry. *	Birmingham. *	Howrah.	Hong Kong. *	Vera Cruz. *
Total kw. installed . . .	164	436	400	600	400	2,100
Maximum load	125	405	400	—	—	1,000
Average load	—	303	—	100	250	—
Plant factor . . per cent.	—	70	50	60	—	—
Station factor	—	75	25	—	—	—
Annual load factor . per cent.	15·4	29·2	21·5	—	—	30
B.T.U.	170,000	517,905	753,100	—	—	1,517,240
Period covered . . months	12	6	12	6	—	7
Average cost of oil-fuel per ton *s.*	70	60	53·5	52	35	40
Lb. of fuel per kw.-hour . .	0·71	0·695	0·703	0·73	0·72	0·71
Overall thermodynamic efficiency	25·70	26·70	26·40	25·9	25·7	26·2
Operating costs per kw.-hour.						
Fuel	0·265	0·225	0·202	0·228	0·134	0·152
Oil, waste, etc.	0·070	0·012	0·036	0·057	—	—
Wages	0·293	0·100	0·133	—	—	—
Maintenance and repairs . .	0·007	0·018	0·055	0·015	—	—
Total . . *d.*	0·635	0·355	0·426	—	—	—

* These five columns were taken from a Table in the *Paper* on "Economics of Medium-sized Power-Stations," by A. J. J. Pfeiffer. Journal, Inst. Electrical Engineers, 1909, vol. 43, page 617.

Discussion.

The **Chairman** (Mr. James Wyness) said he was sure they were all much indebted to Mr. Pursey for his interesting Paper. Prima facie one would expect that in India one of the difficulties from an engine which developed such high pressures was the supervision necessary, but the author had indicated that in his own station at Howrah no special difficulty had been found. It was interesting also, he thought, to recall that the large pumping plant at Divi Island Irrigation Station was operated by Diesel engines, and according to reports furnished, he believed the working had been quite satisfactory.

Then, again, in connection with the Calcutta Municipality, at the Wellington Square station a Diesel engine had been installed, and he understood its performance had been quite satisfactory; but it was a fact that the advantages which were adduced by the chief engineer as a reason for installing it had not been redeemed in the way of upkeep, owing mainly to the enormous increase in the cost of fuel. That seemed to be one of the economic difficulties in dealing with this engine. If one were dealing with a fuel which, as in this case, had shown itself to increase steadily in cost, it was very difficult to say what advantage there would ultimately be.

Professor **Thomas S. Dawson** (Victoria Jubilee Technical Institute, Bombay) said he thought the author of the Paper must have an exceptionally fine set of engines, or be in possession of a very fine staff, to be able to run for such extended periods without repairs. He knew of one instance where the cost of cleaning valves and so forth was so excessive that the owners of the Diesel engine in question had actually discarded using crude oil, and now used a low grade of kerosene, and the working cost came out lower. Another instance was in Bombay, where they had three 400-h.p. sets which had been running for only a few years, and to go there and see the accumulation of cylinder-heads, liners and pistons which had been scrapped was an interesting sight. He thought,

(Professor Thomas S. Dawson.)

however, one must admit that, as a scientific production, as a heat-engine, there was nothing in the shape of a prime mover which could approach the Diesel engine to-day.

There was a very serious point to consider, which their Chairman had raised, and that was the steady increase in the cost of fuel which had taken place during the last three or four years. He remembered, some six years ago in Bombay, one could get crude petroleum at Rs.25 or Rs.26 a ton. To-day it was Rs.46, and there was not a single large company that would make a contract for any lengthened period for the supply of it. It was also open to discussion whether that difficulty with regard to getting crude petroleum would not rather increase than become less. Most, if not all, of the big supply companies found that it really paid them better to distil off the crude oil and sell the lighter and more volatile products, for which there was an established demand. He was discussing this question some time ago with one of the representatives of the Standard Oil Company, who said that in many instances people who had considered the establishment of Diesel engines in America had approached them with a view to working out the cost of both oil- and steam-engines. After due consideration, these people decided that it was not worth while to risk being unable to obtain the fuel at any time when they wanted it.

With regard to the tests mentioned in the Paper, he thought the comparisons would have been more interesting if the cost of the fuel had been given both for the oil- and the steam-engines. In all cases one did not get the same mechanical efficiency out of the fuel, and to give the amount used per indicated horse-power was hardly a statement which was likely to carry conviction, as it depended entirely upon the mechanical efficiency of the plant. He did not infer that it was so in this particular instance, but one might be comparing a Diesel engine at its best with the steam-engine with its boilers dirty, its valves leaking, and everything that tended towards a high coal-consumption. In many cases where Tables of this nature were given they were apt to be misleading.

With regard to the costs of running, he had himself worked out a good many of these figures, having had to give lectures on this subject. Taking the cost of fuel and the mechanical efficiency of the Diesel engine (which of course was very low) into consideration, even in the case of a moderate sized plant—say of 300 or 400 h.p. —the steam-engine was not dead yet. As to the cost of repairs, he thought all would be prepared to admit that where they had exceedingly high pressures and were dealing with cases of a very high temperature, the question of mechanical excellence was much more important than in the case where one was using steam; and with these pressures, one must admit that the workmanship and attention and everything which went towards success must be of an infinite better order than was demanded from the staff of men who were running a steam-plant.

The comparison with the gas-engine of the present day would be exceedingly interesting if carried to its logical conclusion. He had recently seen in Bombay a 1,000-h.p. set working in conjunction with a Westinghouse gas-engine, and there were some interesting figures in connection with this. But seeing that the coal cost in Bombay Rs.14 a ton landed at the mill, the engine, on rather less than two-thirds its full load, was working on 1·2 lb. of coal per i.h.p., or at a cost which would compare, he thought, very favourably with even the best Diesel engines in Bombay; and if they went to larger plant the economy was still more marked.

Mr. G. S. **WILLIAMS** said that Professor Dawson had taken up several points that he was going to bring forward. His (Mr. Williams') opinion was that in some of the smaller sets the Diesel would well hold its own with the small steam-engine, but it really depended upon conditions. The steam-engine was, speaking from the central-station point of view, handicapped on account of stand-by charges, and if they had to keep boilers under steam it all tended to increase the cost of the generation. But as long as they could get steam-engines to run with a good load factor, they could get results that would equal, even in some of the smaller sets, some of the Diesel results. The cost of running had naturally a great deal to do with the price that was paid for the heat-units or the fuel. In the Diesel engine one might use less fuel, but one had to pay a

(Mr. G. S. Williams.)

very high price for it. For coal one used more, but paid less for it. The high thermal efficiency of the Diesel engine could not be attained by the present steam-engine, but in steam-engines, in connection with turbines, etc., the thermal efficiency was being gradually improved. He quite agreed with Professor Dawson as to the increase in the price of fuel-oil. He himself had used it in place of coal at one time, but had to abandon it on account of its high price.

As regards the cost of repairs, he thought it was more than counterbalanced by the difference in the cost of the oil required for lubrication purposes. The oil costs of the Diesel engine appeared to be very much greater than for steam-engines. One of the advantages the makers of the Diesel engine claimed was that the small engines were as economical as the large engines. This was just the opposite in the steam-engine—the larger the plant put in the more economical it was. The author referred to an engine of 240 h.p., and he had given them the results of some tests (page 287), but he had not given them the full figures, such as stores, wages, superintendence charges, etc., which were most important. He would like to compare the test costs which Mr. Pursey had given with that of the same size steam-engines that they had in the Alipur Works. (Mr. Williams then quoted figures comparing the cost of working steam-engines as compared with the Diesel engine.) The result obtained by Mr. Pursey on the test of the Diesel engine came out at 0·13 per b.h.p. The official test of the steam-engine with 150° F. superheat, condensing, gave 13 lb. water per b.h.p. With a good boiler under test this was equivalent with losses, say, to 1·75 lb. coal. Coal, with present price at Rs.7–8 per ton, cost 0·086*d.* against the Diesel test of 0·13*d.*, whereas the mechanical efficiency of the engine was 90 per cent. against 70 per cent. for the Diesel. With larger engines the steam-consumption was less, and in a combination of a 1,000 h.p. engine and exhaust turbine the consumption could be brought down to 10·2 lb. of water.

The author had also given them results of several stations with Diesel engines, including his own at Howrah, but the full particulars of those were not available. He had, however, got some results from his own stations of steam-engines which showed that, although they had to incur stand-by charges, properly managed, under certain conditions they could get as good results from comparatively small steam sets as with the Diesel. As regards the marine engines, he had seen them running, and they were certainly not free from vibration and smell, and they took up considerably more room than the steam sets.

Mr. B. W. **BAGSHAWE** said he would like to draw attention to the question of power generated by gas. It seemed to him that the future in India lay with the gas-engine. It was possible in Calcutta, or anywhere within 400 miles of the coalfields, to produce 126,000 B.Th.U. from coke at a cost of one anna. In Calcutta, which was the most favourable place from the oil-supply standpoint, it was only possible to produce 63,000 B.Th.U. from oil. A Diesel engine would develop 1 b.h.p. from approximately 9,000 B.Th.U. A modern up-to-date gas-engine would develop 1 b.h.p. from 10,000 B.Th.U. It seemed to him that, in Calcutta at any rate, the gas-engine ought to be found much more useful than the Diesel engine. At the same time they ought to realize that there were many other places in India with conditions very different to Calcutta; the tea districts for instance, and districts where it was difficult to get fuel, and in such places there was undoubtedly a great scope, in his opinion, for the Diesel engine. In Ceylon, Diesel engines were working with only coolie labour at altitudes of over 5,000 feet, and were giving results which were quite comparable with the results mentioned in the Paper.

In the Table (page 294) he gave some figures of the comparative costs of Steam, Diesel, and Gas plants, showing that the modern gas-engine appeared to much greater advantage than in the figures furnished by Mr. Pursey. Moreover, a modern gas-engine would not require any more space than a Diesel engine. Without introducing the ammonia plant and including all the stand-by losses of depreciation, upkeep, and interest and everything against the gas-producer, it was possible to produce 1 h.p. at 0·29 of an anna, whereas, under the same conditions with a Diesel engine it would be 0·32.

(Mr. B. W. Bagshawe.)

Means of Production.	Diesel Engine.	Gas-Engine.	Steam-Engine.	Diesel Engine.	Gas-Engine.	Steam-Engine.	Gas-Engine with bituminous coal-gas plant.
Brake horse-power	35	35	35	160	160	160	160
Size of engine-house . . . ft.	12×20×15	12×20×15	10×20×15	20×27×20	20×27×20	17×27×20	20×27×20
Size of boiler-house and gas-producer	—	10×6	14×40×15	—	20×10	20×48×20	30×15
Cost of land at 7*s.* per square yard . £	10	11·6	30	21	28	56	38·5
Cost of buildings . . . . . ,,	90	100	230	180	200	420	200
Engine foundations, etc., boiler settings ,,	10	10	60	35	35	100	35
Engine tanks, piping, and condenser, etc. ,,	585	280	240	1,680	1,140	800	1,140
Boiler or gas-producer and accessories ,,	—	120	290	—	270	600	500
Total capital cost . . . . . ,,	695	521·6	850	1,916	1,673	1,976	1,913·5
Capital cost per brake horse-power . ,,	19·8	14·9	24·3	14·28	10·45	12·4	12·0
Annual Charges.							
Interest on capital, 4 per cent. . ,,	27·8	20·8	34	76·64	66·9	79	76·5
Building: maintenance and depreciation, 5 per cent. . . . . . £	4·5	5	11·5	9·0	10	21	10·0
Engines and machinery: maintenance and depreciation, 10 per cent. . £	58·5	28	24	168	114	80	114
Boilers: maintenance and depreciation, 12 per cent. . . . . . £	—	—	35	—	—	72	—
Gas-producer depreciation, 5 per cent. ,,	—	6	—	—	13·5	—	25·0
Fuel . . . . ,,	47·25	50	130	186	190	440	78
Lubricant, waste, etc. . . . . ,,	20	20	20	55	55	55	55
Wages, removal of ash, etc. . . . ,,	75	75	95	87·5	87·5	140	87·5
	233·05	204·8	350	582	536·9	887	446
Annual cost per brake horse-power . ,,	6·66	5·85	10	3·63	3·35	5·5	2·78
Cost per brake horse-power hour . anna	0·59	0·52	0·89	0·32	0·29	0·49	0·24

1 Rupee = 1*s.* 4*d.* 1 Anna = 1 Penny.

The Diesel engine required to be well looked after, for if they had a pressure of 500 lb. per square inch in the cylinder, and put it in charge of a coolie, trouble would probably ensue. There were gas-engines in different parts of India of over 100 h.p. being run by men who were paid Rs.30 a month, and the only time they were ever inspected by Europeans was once a year. A gas-engine, after running for many years under these conditions, gave practically as good results as when new, and would develop 1 b.h.p. on 1½ lb. of India coke.

Professor W. H. EVERETT said that in one or two cases where his opinion had been asked with regard to the installation of Diesel engines, he had found it his duty to advise against it, but at the same time he had kept an open mind on the subject. About a year ago he spent some months in Germany and Switzerland, and in the course of his travels he visited several of the larger works in different places, where he was very much struck by the number of Diesel engines which were being built. One very striking case was a factory which, when he visited it last about a dozen years ago, was entirely occupied with the manufacture of a famous type of horizontal steam-engine, but which now confined its production almost entirely to Diesel engines. Another place he went to was the Koerting works, where they made a good number of Diesel engines, as well as oil-engines of other types; contrary to the usual practice, the Koerting engines were governed by varying the stroke of the fuel-pump automatically. He could give some figures for the oil-consumption per effective horse-power hour, such as in the case of equal-sized, two-stroke engines and four-stroke engines. With the two-stroke the figure was 0·44 lb. and with the four-stroke 0·39 lb., which of course was considerably better, and these engines ran more quietly. He would like to ask Mr. Pursey two questions, namely, whether he had had any sort of trouble with these engines, and also what kind of labour he had in charge of them.

Professor THOMAS S. DAWSON said he would like to say just a word or two more with regard to tests he had to carry out recently in Bombay, with some of the large mill-engines, in view of the proposals of the Tata Hydro-electric Co., who were installing something like 60,000 h.p., and would probably revolutionize the mill industry in Bombay. They proposed to supply electricity at 0·55 of an anna per unit, to install all the motors, keep them running, and renew any that might break down. The question arose in the minds of a good many of these mill-owners as to whether the scheme would be worth entertaining or not, and he was requested to work out tests at some few different mills, where the horse-power would probably be about 1,000 or 1,800, to see what their actual cost of working was at the present time. Most of these engines were about 15 to 20 years old: therefore the figures would come rather as a surprise to people who imagined that steam was on its last legs. Taking 5 per cent. interest on capital cost invested, plus 5 per cent. depreciation in all cases, as being the basis on which these costs were worked out, and the load taken on the actual horse-power transmitted into the machines, including the capital charges, interest, and depreciation, the figures per actual horse-power in the machines worked out at 0·332, 0·334, 0·317, 0·346 of one anna per horse-power. Moreover, the engines were not all of the same type, and ran with steam pressures varying from 120 to 160 lb. These figures came between 0·312 and 0·399 of an anna per horse-power, and if one transferred that into units of electricity it would be seen that even then most of the mills in Bombay could run with their old engines, and still compete fairly successfully with electricity at 0·55 of an anna per unit.

Mr. PURSEY said in reply to the discussion, that Mr. Wyness had referred to the high pressures and the difficulties therewith. Of course that was simply a question of mechanical design. Professor Dawson referred to the cleaning and pitting of valves. It must be admitted that this did to a great extent depend upon the fuel which was being burnt. In his experience at home, on the engines running with Texas oil, it was necessary to take out the valves and grind them to the seatings about every two days, but in Calcutta, running with Borneo oil, it was only required about once a month. Professor Dawson also referred to the cost of oil in the last test. When that test was taken the oil cost Rs.33 a ton; it was now Rs.41.

Mr. Williams had criticized the Table on page 284. These figures had been taken from the actual official records from all stations below 1,000 horse-power in Great Britain; and when Mr. Williams mentioned what his engines at Alipur could do he was rather theoretical. These in the Table were actual figures.

Professor Everett asked for the cost of labour. It was necessary in the station at Howrah to have a foreman, more for electrical work than anything else. The men who actually ran the engines were fitter drivers earning from 21 to 24 rupees a month. They had had absolutely no breakdowns of any description over there, and he did not think that the whole time the plant had been running (5 years) the supply had ever been taken off the line from any defect due to the engines. He thought that the criticism all tended to the price of oil, which was a most serious drawback, but he did not think that in any way prejudiced the actual thermal efficiency of the Diesel engine, which was obviously greatly higher than either gas or steam. Looking at it from the commercial point of view was of course a very different thing, but to-night he assumed they were looking at it from the engineering point of view. The criticism, he considered, tended on the whole rather in favour of the Diesel engine.

The CHAIRMAN (Mr. James Wyness) in bringing the meeting to a close said he wished to propose a hearty vote of thanks to Mr. Pursey for his excellent Paper, and to the gentlemen who had contributed to the discussion. He thought they had had one of the most interesting and informing discussions that were to be found recorded in their Minutes.

MEMOIRS.

Sir John Gay Newton Alleyne, Bart., was born at Barbados on 8th September 1820, being the son of Sir Reynold Abel Alleyne, Bart. Though the Baronetcy was created in 1769, Sir John, who succeeded his father in 1870, was only the third holder of the title. He was educated at Harrow and at the University of Bonn, and from 1843 to 1851 was Warden of Dulwich College; it was claimed that he was related to Edward Alleyn, the Founder of that establishment. After a short engagement at Barbados in the sugar industry, he entered the service of the Butterley Iron Works in Derbyshire, and in 1852 he assumed the direction of the Butterley Company's extensive collieries, iron works, engineering and other departments, employing about 7,000 workmen. One of the first manufactures which engaged his attention was that of rolled-iron girders for floors, and deck beams for iron ships. In 1853 Messrs. Fox and Barrett introduced their system of fire-proof flooring, for which the Butterley Company supplied the rolled girders or joists. A great demand arose and the capabilities of the mills then in use were soon exceeded, but he introduced his system of welding which enabled the largest sections required to be produced without unduly taxing the capacity of the small rolling-mills then in operation. In the Exhibition held in London in 1862 the largest exhibit in iron and steel was that made by this company, and every item in this exhibit was made under Mr. Alleyne's personal supervision. The Bessemer and other processes for cheap steel had not been introduced when Mr. Alleyne turned his attention to manufactures in iron; and, owing to the increasing difficulty of obtaining good puddlers, in 1867 he devised a puddling furnace with a rotating circular bottom combined with a reciprocating mechanical rabble. About this time he designed and made a two-high reversing mill for rolling iron and steel girders and deck beams up to 16 inches deep, fitted with traversing tables, movable saws, and other appliances which only appeared at a much later date at other works. In 1868 the Butterley Company secured the contract for the large roof of St. Pancras Station, London, which has a span of 240 feet springing from rail level to a height of 102 feet, with 24 main ribs weighing about 60 tons each, for the erection of which he designed two timber stages fitted with power-driven hoists for lifting the ironwork into position. In 1872 the same company undertook the manufacture and erection of the large double-line railway bridge over the Old Maas at Dordrecht, which was a heavy and difficult work; and another piece of work of a different kind, which was carried out under his supervision, was the 84-inch cylinder Cornish pumping engine for the Clay Cross Collieries. Numerous other large works were also carried out whilst the development of the Butterley Company's collieries, blast-furnaces and forges, and many minor works, was in progress. Nor were his labours confined to practical ordinary work. He was a skilled astronomer, having a well-fitted observatory; and the method of determining small quantities of phosphorus in iron and steel by means of the microscope was devised by him. He received no engineering education whatever; it was all natural genius, except that during the time he was Warden of Dulwich College, he occasionally attended the works of Messrs. Pontifex and Co. On his retirement from business, he removed his astronomical instruments to Chevin, near Belper, where he was able to devote more time to such work, and was especially interested in the study of sun spots and their relation to meteorological conditions. His death took place at his residence in Falmouth on 20th February 1912, at the age of ninety-one. He became a Member of this Institution in 1865; he was also a Member of the Institution of Civil Engineers, and one of the original Members and Vice-President of the Iron and Steel Institute.

EDMUND GEORGE AUSTIN was born near Seringapatam, Mysore, India, on 5th October 1873. He was educated at a private school in Clifton, Bristol, and at Dover College from 1889 to 1892, when he went to the University College, Bristol, for a year. In 1893 he commenced an apprenticeship at the locomotive works of Messrs. Peckett and Sons, Bristol, and in the following year was engaged at the Bristol Docks until 1896, when he went to the Taff Vale Railway Locomotive Works at Cardiff. On leaving these works in May 1897, he went to sea as Third Engineer for one year, and then joined the P. and O. Steamship Co. in March 1898. Two years later he obtained his certificate as Second Engineer, and in March 1901 he was appointed assistant locomotive superintendent of the Bengal-Nagpur Railway at Khargpur. After a year he was transferred to Calcutta to take charge of the railway workshops and to be superintendent engineer of the fleet of ferry steamers and launches. Subsequently he became district locomotive superintendent of the same railway, until ill-health caused him to take sick leave in November 1904. He returned to India in the following spring as assistant locomotive superintendent at Khurda Road. Latterly he was acting district locomotive superintendent, but was obliged to return to England in June 1911 on sick leave. His death took place at Bournemouth on 18th February 1912, at the age of thirty-eight. He became a Member of this Institution in 1905.

ADAM CARLISLE BAMLETT was born at Great Smeaton, near Darlington, on 31st May 1835. At about the age of twenty-five he went to Thirsk and commenced business in a small way as a maker of agricultural implements. By dint of continual experimenting, he so improved the construction of his various products that the business rapidly increased both at home and abroad, and he was rewarded with the success of his machines in competition at Agricultural Meetings and by the award of various medals at the Paris Exhibitions of 1878 and 1889 and at other exhibitions. In addition to being the largest employer of labour in Thirsk, he was prominent in local affairs, being for many years a member of the Thirsk Rural Council and representing the town on the North Riding County Council. He was also chairman of the Sowerby Parish Council. He had been in failing health for a considerable time, and his death took place at Sowerby on 10th January 1912, in his seventy-seventh year. He became a

Member of this Institution in 1887; he was also a Member of the Iron and Steel Institute.

Matthew Wilson Barker was born at South Shields on 12th February 1863. He served his apprenticeship from 1878 to 1884 in the shops and drawing office of the Silksworth Colliery, Sunderland, where he afterwards acted as assistant engineer. He then attended a course of lectures on Mining at the Royal School of Mines, and in 1885 returned to Sunderland where he was engaged in business as engineer and surveyor, as well as instructor of mining and engineering, etc., at Dr. Rutherford's Science Schools, Newcastle-on-Tyne, and other places. In 1888 he was appointed chief surveyor to the De Beers Consolidated Mines, South Africa, and in 1892 became assistant to Mr. Sidney H. Farrar, also acting as manager to Messrs. Howard, Farrar and Co., engineers, of Johannesburg. Three years later he was appointed consulting engineer to the East Rand Proprietary Mines, New Kleinfontein Gold Mining Co., and other companies, and in 1898 he returned to England. From 1898 to 1904 he acted as consulting engineer to Messrs. Farrar Brothers, London, and in the latter year he was appointed general manager and consulting engineer to the Penhalonga Proprietary and Rezende Mines, Rhodesia. Owing to ill-health he returned to England in 1908. His death took place at his residence in Sydenham, London, on 15th January 1912, in his forty-ninth year. He became a Member of this Institution in 1896.

Samuel Waite Johnson was born at Bramley, near Leeds, on 14th October 1831, being the son of Mr. James Johnson, of Leeds, an engineer who was in the service of the Great Northern Railway Co. He was educated at the Leeds Grammar School, with the intention of his being trained as an engineer, and when quite young he was apprenticed to Messrs. E. B. Wilson and Co., Railway Foundry, Leeds. While there he was a pupil of the late Mr. James Fenton, who was a partner in the firm, and he assisted in the design of the celebrated "Jenny Lind" type of engine, of which so many were built by Messrs. Wilson and Co., and he was also engaged on the equally well-known "Bloomer" type introduced on the Southern Division of the London and North Western Railway by Mr. McConnell. On leaving this firm he obtained the appointment of assistant district locomotive superintendent on the Great Northern Railway, and in 1859 was appointed acting locomotive superintendent of the Manchester, Sheffield and Lincolnshire Railway at Gorton. There he remained five years, until he was promoted to the position of locomotive superintendent of the Edinburgh and Glasgow Railway Co., which was subsequently amalgamated with the North British Railway Co. in 1865, when he was made locomotive superintendent of the western district, including the Monkland Railway, until 1866. He next became locomotive engineer of the Great Eastern Railway at Stratford, a post he occupied until 1873, when he was appointed head of the locomotive works of the Midland Railway at Derby, on the death of Mr. Matthew Kirtley. This office he held for over thirty years, retiring at the end of 1903. During this period he was also locomotive engineer of the Somerset and Dorset Joint Railway, a line which ran from Bath to Bournemouth, and of the Midland and Great Northern Joint Railway, a line connecting the Midland Railway with Cromer and Yarmouth. While with the Midland Railway Co. Mr. Johnson initiated many important changes in the design and construction of locomotives. His four-wheel coupled express bogie engine "Beatrice" took the Gold Medal at the Saltaire Exhibition in 1877, and his single-driving-wheel express passenger engine, No. 1853, with bogie in front, won the Grand Prix at the Paris Exhibition of 1889. A larger class of engine was designed by him after 1900, in which the size of the boiler was increased, and the working pressure raised to 195 lb. per square inch. These locomotives were of the compound type and had three cylinders in place of two. He also designed and constructed some very powerful goods locomotives during the latter years of his office; and he adopted piston-valves on his engines, being a firm believer in them when properly constructed.

Mr. Johnson became a Member of this Institution in 1861, and was elected a Member of Council in 1884. In 1895 he became a

Vice-President, and President in 1898. His Presidential Address * contained much valuable information relating to locomotives, railway traction, and kindred matters. On the occasion of the Summer Meeting of this Institution in Derby during his Presidency, in 1898, Mr. Johnson was honoured by the generous welcome that was accorded to the Members by the Midland Railway Co.; and a visit to Nottingham was enhanced by the Reception and Garden Party that he gave in the grounds of the ancient Castle. He resided for many years in Nottingham, but took little part in public life; he was, however, a Justice of the Peace for that city. His death took place at Nottingham on 14th January 1912, at the age of eighty. He was a Member of the Institution of Civil Engineers.

JOHN KERSHAW was born at Abingdon on 3rd January 1827. He was articled to Mr. John V. Gooch, locomotive superintendent of the London and South Western Railway at Nine Elms, and in 1850 went with him to the (then called) Eastern Counties Railway, as one of the three engineering superintendents. Whilst there, and on the London and South Western Railway, he conducted many experiments on the consumption of fuel and the resistance of air in locomotive engines. In 1851 he became superintendent at Dover, under Mr. Cudworth, for whom he made important experiments in the economic working of the Crampton engine as compared with the standard express engines of that line. In the following year he was appointed Locomotive Engineer of the Midland Great Western Railway of Ireland until June 1854, when shortly afterwards he superintended the construction of the Railway-Carriage and Wagon Building Works at Oldbury, near Birmingham. In the following year he was appointed Locomotive Engineer of the Great Indian Peninsula Railway, at Bombay, and accomplished the difficult work of superintending the railway from the top of the Bhore Ghaut to Poona, and for the complete success of this undertaking received the thanks of the Indian

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* Proceedings, I.Mech.E., 1898, Part 2, page 149.

Government. Owing to ill-health, induced by his arduous labours in an unhealthy climate, he resigned and left India in 1860. He designed the 10-wheel bogie-engines for working the Bhore Ghaut incline, the ruling gradient of which is 1 in 37, and as evidence of their suitability, they are still at work, and were the precursors of the bogie-engines now used on the principal English lines. In the starting of the first cotton mills in Bombay, by some of the leading native merchants, he was professionally consulted. In after life he was connected with the firm of Sharp, Stewart and Co., late of Manchester, and also with the Oldbury Carriage Works, near Birmingham. His death took place, after a short illness, in London, on 20th February 1912, at the age of eighty-five. He became a Member of this Institution in 1866; he was also a Member of the Royal Society of Arts and of the Royal Zoological Society. [S. W. K.]

GEORGE ELLIOT LAWES was born at Aberdare, South Wales, on 1st July 1869. He received his early training as an engineer under Mr. E. M. Hann in the Powell Duffryn Works at Aberdare. On the termination of his apprenticeship in 1889, he went to Buenos Aires and served for five years on the Port Works and with the Buenos Aires Great Southern Railway in the capacity of fitter, valve-setter, and later trial engine driver, taking up the position in 1894 of Acting Locomotive Superintendent of the Argentine North East Railway, where he introduced many labour-saving appliances. In 1904 he became Locomotive and Stores Superintendent of the Paraguay Central Railway, in which country he was the only representative of the Institution, acting also as magistrate, doctor, and chief constable of the little township inhabited by the workmen and their families. Three years later he transferred his services to the Peruvian Central Railway in the same capacity and, after a short holiday, was engaged in July 1911 as Stores and Locomotive Superintendent of the Brazil North Eastern Railways, a new company. His intimate knowledge of the Spanish language and customs, combined with his experience in so many of the republics of Latin America, placed him amongst the highest authorities on the management of native labour on railways in those republics. One of his inventions was an oil-burner which dispensed with the necessity of introducing cold air into the furnace. It was fully experimented with and proved highly successful, effecting a saving of 30 per cent. in oil over other burners. He died at Ceara, Brazil, after a short illness, on 14th February 1912, of yellow fever, at the age of forty-two. He became a Member of this Institution in 1904; he was also a Member of the Royal Society of Arts.

FitzCharles Macdonald was born at Strachur, Argyllshire, on 9th June 1856. He was educated at Glasgow High School and Glasgow University, and began in 1873 an apprenticeship of four years with Messrs. J. Norman and Co., engineers, of Glasgow. On its completion he spent two years in the locomotive works of the Caledonian Railway Co., in Glasgow; and during the years 1873–79 he also attended classes at the Glasgow School of Arts. Having decided to follow a career abroad, he sailed in 1880 for Rangoon, where he obtained a post with the Irrawaddy Flotilla Co. In 1886 he became assistant superintendent to the same company, and from 1894 to 1901 he acted as superintendent engineer at the Dalla Dockyard, Rangoon. He was an enthusiast in military affairs, and was associated with the Rangoon Submarine Mining Engineers, of which he had command for a period. He saw active service in the Burmese war of 1885, and was present at the surrender of King Thebaw in the palace of Mandalay. On behalf of the Indian Government and the Irrawaddy Flotilla Co., he visited the United States in order to study the system of conservancy adopted in regard to the Mississippi, and much of what he learned in America was turned to useful purpose in improving the navigation of the Irrawaddy. Returning home in 1901, he made his headquarters in Glasgow, where he founded the firm of F. C. Macdonald and Co., exporters of all classes of engineering material to Burma, China, and the East generally. He purchased the estate of Glenbranter, Argyllshire, and took an active interest in the affairs of his native parish of Strachur, serving for some time on the School Board.

His death took place at Bombay, where he was staying on business, on 2nd February 1912, in his fifty-sixth year. He became a Member of this Institution in 1901.

Stewart McPherson was born at Dundee on 24th August 1852. He was educated at Wallacetown Public Schools, Dundee, and served his apprenticeship from 1868 to 1873 in the works of Messrs. Gourlay Brothers, Dundee, and Messrs. W. Halley and Sons, Dundee. On its completion he was engaged as engineer and mechanic in the works of Messrs. Baxter Brothers, of Dundee, where he remained until 1879 when he became superintendent of Messrs. Wallis and Pollock's Works, at Cork. In 1881 he was appointed engineer to the Barnagore Jute Factory, Calcutta, and four years later he was promoted to be manager of the same works. This position he held until his return to Scotland in 1911. On the formation of the Calcutta and District Section of this Institution in April 1908 he presided at the Inaugural Meeting of the Section. His death took place at his residence in Dundee, on 21st January 1912, at the age of fifty-nine.

Robert Thomas Middleton was born at Tynemouth on 14th August 1842. His apprenticeship was served at the Elswick Engine Works of Sir W. G. Armstrong and Co., Newcastle-on-Tyne, from 1857 to 1862, and he continued to work there as a journeyman until October 1863. In the following year he was employed at the Wolverton Works of the London and North Western Railway as a mechanic in the erecting shop, and in January 1865 he was engaged as foreman at the Victoria Docks of the London and St. Katherine Dock Co. This post he held until 1869, when he went to India and entered the service of the Bombay, Baroda and Central India Railway as superintendent of bridge work. He continued in this position until his retirement in 1899. During the thirty years he was with the company he carried out the erection of many large structures, including the repair and renewal of girders, which was done without delay to the traffic. His death took place at Ilford, Essex, on 27th October

1911, at the age of sixty-nine. He became a Member of this Institution in 1891.

WILLIAM GREGORY NORRIS was born at Coalbrookdale on 17th December 1829. Having been educated at Sidcot and Ackworth Schools, he entered the service of the Coalbrookdale Company in 1848, and became general manager in 1868. In 1881, on the conversion of the company into a limited company, he was made managing director, and until the close of his life he remained an active director of this company. During the period of his connection with the works,* which date back to the early part of the seventeenth century, many interesting structures, etc., were produced, such as the chequered plate gates, shown at the 1851 Exhibition, and now in Town Hall Park, Warrington, also the Albert Edward cast-iron arch over the River Severn at Coalbrookdale, and many other cast-iron bridges in the country. He devoted his legal and general business knowledge to helping in the public work of the district, and especially was this the case in educational matters. His death took place at Coalbrookdale, Salop, on 8th December 1911, shortly before his eighty-second birthday. He became a Member of this Institution in 1868; he was also a Member of the Iron and Steel Institute.

THOMAS PURVIS REAY was born at South Shields on 13th October 1844. He commenced his engineering career as an apprentice with Messrs. Kitson, Thompson and Hewitson, locomotive engineers, of Leeds, and after passing through the works, he entered the drawing office where he became a highly skilled draughtsman. After some years' experience in that capacity he was appointed works manager, subsequently becoming partner, managing director, and after the death of Lord Airedale in March 1911, chairman of Kitson and Co., Ltd. He possessed indomitable energy and skill, and besides having an intimate knowledge of locomotive engineering in all its branches, and being instrumental in furthering the evolution and development of locomotive practice to meet the constant growth of modern requirements, he had also considerable experience in designing and manufacturing rolling-mill and blowing engines. He was greatly interested in the early application of steam-engines for tractive purposes on tramways, and his knowledge of general engineering was of an extensive character. His death took place suddenly at his residence at Weetwood Lodge, Leeds, on 22nd February 1912, at the age of sixty-seven. He became a Member of this Institution in 1882, and was appointed a Member of Council in 1906, a position which he held at the time of his death. He was also a Member of the Institution of Civil Engineers and of the Iron and Steel Institute.

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* For an account of some of the early productions of these Works, *see* Paper on the "Newcomen Engine," by Henry Davey, Proceedings, I.Mech.E., 1903, Part 4, Appendix I (page 673).

DAVID SOUTER-ROBERTSON was born in Edinburgh on 24th March 1863, being the eldest son of the late Mr. Stewart Souter-Robertson, D.L., J.P., of Lawhead, Lanarkshire. He served his apprenticeship from 1879 to 1884 in the works of Messrs. Walker, Henderson and Co., of Glasgow, and in the locomotive shops of the Midland Railway. In May 1884 he entered the employment of Messrs. F. Leyland and Co., of Liverpool, as a sea-going engineer; he remained in that position until 1887, when he resigned and proceeded to India to join the staff of West's Patent Press Co., being appointed engineer and agent for that company at Saharanpore, North Western Provinces. In 1890 he entered the service of the Indian Government as assistant superintendent of the Canal Foundry and Workshops at Roorkee, United Provinces, and was promoted to be superintendent in 1902. He returned home on sick leave in April 1911, but his health did not improve, and his death took place at Lapford, North Devon, on 20th March 1912, shortly before his forty-ninth birthday. He became a Member of this Institution in 1889.

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1912.

An Ordinary General Meeting was held at the Institution on Friday, 19th April 1912, at Eight o'clock p.m.; Edward B. Ellington, Esq., President, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and that the following sixty-eight candidates were found to be duly elected:—

MEMBERS.

Calvert, Robert,	London.
Clark, Robert Leaver, Major A.O.D., D.S.O.,	Devonport.
Cockey, George Herbert, Engineer Commander R.N., D.S.O.,	London.
Cooke, Charles John Bowen,	Crewe.
Corrin, Harold Rodolph,	Sheffield.
Cripwell, Fred,	Newcastle-on-Tyne.
Dashper, Edward Henry,	Southampton.
Gass, William George,	Bolton.
Graham, Arthur John Wood,	Lincoln.
Julius, George Alfred,	Sydney.

Loving, Henry Croxton,	Sheffield.
MacIntyre, Nicol,	Kirkcaldy.
Penwarden, Charles William Harry,	Jubbulpore.
Riddell, Henry,	Belfast.
Tyrrell, James,	Cirencester.
Wilkinson, Leonard Marshall,	Leeds.
Wilson, Charles,	Kuala Lumpur.

ASSOCIATE MEMBERS.

Bainbridge, Albert Wallis,	London.
Baker, William George,	Portland.
Bamford, William,	London.
Black, James,	Manchester.
Davies, Bertie Trevor,	Swansea.
Douglass, Percy Cuthbert Douglass,	London.
Engert, Frederick Percy,	Doncaster.
Gregory, Hugh Hamilton,	London.
Gurmin, Ernest Willis,	West Bromwich.
Harrison, Douglas Roy Dilworth,	London.
Harrison, William Goldsbrough,	Middlesbrough.
Johnston, Alexander Davidson, Jun.,	Manchester.
Jupp, William Dallas Lony,	Antofagasta.
Kennedy, Albert Vincent,	London.
Kibbler, Howard,	London.
Kohler, Frederic,	Bombay.
Maw, Arthur Ernest,	Detroit, Mich.
Menezes, Antonio Gomes de,	Pará.
Moss, Francis Charles,	Rotherham.
Pannell, John Robert,	Teddington.
Parsons, Joshua,	Derby.
Potts, Samuel,	London.
Price, Owen Alfred,	Glasgow.
Redding, Frederick Chapman,	Cossipore.
Rielley, Peter,	Shanghai.
Ries, Adolph Hulett,	Ipswich.
Romans, Arthur Howard,	Darlington.

Rowell, Henry Snowden,	Berlin.
Sargent, Tom,	Bristol.
Thompson, Albert Edward,	Valparaiso.
Thorpe, Harold Thomas Emmerson,	Johannesburg.
Whitaker, Philip Holt,	Blackburn.
Whitelegg, Stanley Herbert,	London.
Woodfield, Charles Henry,	London.

GRADUATES.

Abbey, Charles Garfield,	Manchester.
Beck, John Wilson,	London.
Clews, Roland Trevor,	Stony Stratford.
Darbishire, James Thurstan Dukinfield,	London.
Dickson, Hugh Spencer,	Doncaster.
Illingworth, Howard Seymour,	Eastleigh.
Kempe, Irwin Trevanion,	Bristol.
Lawton, Herbert A.,	London.
Linley, Percy,	London.
Littledale, Edmund Harold,	Stony Stratford.
Mansell, Laurence Thomas George,	Eastleigh.
Norris, Reginald,	Grantham.
Pollard, Harold,	Halifax.
Scotcher, William Goodliff,	London.
Vince, Jack Sergeant,	London.
Whitehead, Reginald,	London.
Wilson, Archibald Hope,	Bulawayo.

The President announced that the following four Transferences had been made by the Council:—

Associate Members to Members.

Gore, George Ernest,	Middlesbrough.
Holmes, Robert Blake Worsley,	Lagos.
Matthews, William Edward,	Cardigan.
Smith, Edward Turner,	Lagos.

The following Paper was then read and partly discussed:—

"Tenth Report to the Alloys Research Committee: On the Alloys of Aluminium and Zinc. (With an Appendix on a Ternary Alloy of Aluminium with Zinc and Copper)"; by WALTER ROSENHAIN, D.Sc., and S. L. ARCHBUTT, of the National Physical Laboratory, Teddington.

The Meeting terminated at Ten o'clock. The attendance was 76 Members and 47 Visitors.

ANNIVERSARY DINNER.

The Anniversary Dinner of the Institution was held at the Hotel Cecil, Strand, London, on Thursday evening, 18th April 1912. The President occupied the Chair; and the following were among the Guests who accepted the invitations sent to them, although those to whose name an asterisk (*) is prefixed were unavoidably prevented at the last from being present:—

*Vice-Admiral H.S.H. Prince Louis of Battenberg, G.C.B., G.C.V.O., K.C.M.G., Second Sea Lord; The Right Hon. Lord Montagu of Beaulieu; The Right Hon. Sir George H. Reid, G.C.M.G., High Commissioner for the Commonwealth of Australia; Major-General Sir Charles F. Hadden, K.C.B., Master-General of the Ordnance; Surgeon-General Sir Alfred Keogh, K.C.B., LL.D., F.R.S., Rector of the Imperial College of Science and Technology; Lt.-Colonel Sir James R. Dunlop Smith, K.C.S.I., C.I.E., Political A.D.C. to the Secretary of State for India; Colonel Sir Edward W. D. Ward, K.C.B., K.C.V.O., Permanent Under Secretary of State for War; Rear-Admiral A. G. H. W. Moore, C.V.O., Director of Naval Ordnance and Torpedoes; Brigadier-General S. B. Von Donop, Director of Artillery; Colonel Sir H. W. W. Barlow, Bart., Superintendent, Royal Laboratory, Woolwich; Colonel H. C. L. Holden, C.B., F.R.S., Superintendent, Royal Gun and Carriage Factories; *Councillor John M. Gatti, Mayor of the City of Westminster; Sir Thomas Matthews, Engineer-in-Chief, Trinity House; Sir Henry Tanner, I.S.O., Architect, H.M. Office of Works; Mr. F. G. Ogilvie, C.B., Secretary, Science Museum; Mr. E. B. Barnard, Chairman, Metropolitan Water Board; *Mr. Frank Ree, General Manager, London and North Western Railway; Dr. T. Gregory Foster, Provost, University College, London; *Sir Alexander R. Stenning; *Mr. Robert Thompson, M.P.

Agents-General for the Colonies: The Hon. Sir Newton J. Moore, K.C.M.G. (Western Australia); The Hon. Sir J. W. Taverner (Victoria); *Major Sir Thomas B. Robinson (Queensland);

The Hon. A. A. Kirkpatrick (South Australia); The Hon. Sir John McCall, M.D. (Tasmania); Mr. T. G. White (Secretary, New South Wales).

Presidents of Technical Institutions: Dr. W. Cawthorne Unwin, F.R.S. (The Institution of Civil Engineers); Sir William Ramsay, K.C.B., LL.D., F.R.S. (British Association); *Mr. W. E. Garforth (Institution of Mining Engineers); Colonel R. Saxton White, V.D. (North-East Coast Institution of Engineers and Shipbuilders); Mr. E. Hall-Brown (Institution of Engineers and Shipbuilders in Scotland); * Mr. Charles Day (Manchester Association of Engineers); *Mr. Summers Hunter (Institute of Marine Engineers); *Professor William Gowland, F.R.S. (Institute of Metals); Mr. L. Alphonse Legros (Institution of Automobile Engineers); Mr. Edward Hooper (Institution of Mining and Metallurgy); *Mr. Walter Dixon (West of Scotland Iron and Steel Institute); Mr. Charles H. Wall (Birmingham Association of Mechanical Engineers); Mr. G. Blake Walker (Sheffield Society of Engineers and Metallurgists); Mr. A. E. Penn (Chairman of Council, Association of Engineers in Charge).

Dr. J. H. T. Tudsbery, Secretary, Institution of Civil Engineers; Mr. R. W. Dana, Secretary, Institution of Naval Architects; Mr. G. C. Lloyd, Secretary, Iron and Steel Institute; Mr. Leslie S. Robertson, Secretary, Engineering Standards Committee; Mr. J. K. Aykroyd, Chairman, Graduates' Association; Mr. S. A. Smith, Hon. Secretary, Graduates' Association.

*Professor J. O. Arnold, D.Met.; Mr. R. Godfrey Aston; Mr. S. L. Archbutt; *Mr. A. E. L. Chorlton; Mr. F. L. Cunningham; Mr. F. W. Harbord; Professor A. K. Huntington; *Mr. A. Huson, F.Inst.B., Institution Treasurer; *Mr. James Miller; Mr. L. Pendred; Dr. Walter Rosenhain; Dr. T. E. Stanton.

The President was supported by the following Members of the Council:—*Past-Presidents:* Mr. John A. F. Aspinall; Sir Alexander B. W. Kennedy, LL.D., F.R.S.; Mr. William H. Maw, LL.D.; Sir William H. White, K.C.B., LL.D., F.R.S.; and Mr. J. Hartley Wicksteed. *Vice-Presidents:* Sir H. Frederick Donaldson, K.C.B.; and Dr. W. Cawthorne Unwin, F.R.S. *Members of Council:* Mr.

William H. Allen; Mr. Dugald Clerk, F.R.S.; Dr. H. S. Hele-Shaw, F.R.S.; Mr. George Hughes; Mr. William H. Patchell; Mr. Mark H. Robinson; and Captain H. Riall Sankey, R.E., ret.

After The President had proposed the loyal toasts, Sir H. Frederick Donaldson, K.C.B., Vice-President, proposed that of "The Empire," which was acknowledged by The Right Hon. Sir George H. Reid, G.C.M.G., High Commissioner for the Commonwealth of Australia.

The toast of "Our Guests" was proposed by The President, and acknowledged by The Right Hon. Lord Montagu of Beaulieu and Dr. T. Gregory Foster, Provost of University College, London.

The concluding toast of "The Institution of Mechanical Engineers" was proposed by Sir William Ramsay, K.C.B., LL.D., F.R.S., President of the British Association, and acknowledged by The President.

The Institution of Mechanical Engineers.

PROCEEDINGS.

May 1912.

An Extra General Meeting was held at the Institution on Friday, 3rd May 1912, at Eight o'clock p.m.; **Edward B. Ellington**, Esq., President, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The Discussion upon the Tenth Report to the Alloys Research Committee was resumed and concluded.

The Meeting terminated shortly before Ten o'clock. The attendance was 64 Members and 23 Visitors.

TENTH REPORT* TO THE ALLOYS RESEARCH COMMITTEE: ON THE ALLOYS OF ALUMINIUM AND ZINC.

(With an Appendix on a Ternary Alloy of Aluminium with Zinc and Copper.)

By WALTER ROSENHAIN, D.Sc., and S. L. ARCHBUTT,
of the National Physical Laboratory, Teddington.

TABLE OF CONTENTS.

PAGE
General Introduction . . . 323
Summary of Principal Results— . . . 327
  Constitution of the Alloys . . . 327
  Study of Cast Alloys . . . 328
    "Ageing" of Castings . . . 329
  Study of Wrought Alloys— . . . 330
    Condition for highest Ultimate Stress (Table) . . . 331
    Ternary Alloy 25/3 . . . 336

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* For the previous Reports, *see* Proceedings as follows:—

First, 1891, p. 543; Second, 1893, p. 102; Third, 1895, p. 238; Fourth, 1897, p. 31; Fifth, 1899, p. 35; Sixth, 1904, pp. 7, 859, and 1319; Seventh, 1905, p. 859; Eighth, 1907, p. 57; and Ninth, 1910, p. 119.

A Paper upon "The Constitution of the Alloys of Aluminium and Zinc" was contributed by the same Authors to the Royal Society. (*See* Phil. Trans. March 1912).

MAIN REPORT.

PAGE

- *Plan of Research* 337
- *Constitution of the Alloys* 337
  - Equilibrium Diagram— 338
    - Experimental Evidence for 339–42
    - Range of the Eutectic 339
    - Formation of a Compound Al_2Zn_3 340
    - Duplex Structure formed by decomposition of this Compound at 256° C. (493° F.) 341
    - Typical Cooling Curves 343
    - Bearing of Diagram on Mechanical Properties . . . 343
- *Study of Cast Alloys* 344
  - Materials used 344
  - Method of Preparation 344
  - Production of Sound Castings 346
  - Composition of Alloys 347
  - Tensile Tests on Cast Alloys—
    - Sand-Castings 348
    - ,, ,, "Ageing" Tests 352–4
    - Chill-Castings 354
  - Specific Gravity of Cast Alloys 356
  - "Specific Tenacity"— 359–62
    - Sand-Castings 360
    - Chill-Castings 360
  - Compression Tests— 362
    - Chill-Castings 363
    - Sand-Castings 363
- *Microstructure of Cast Alloys* 365
  - Formation of "Cores" 365
  - Influence of Compound Al_2Zn_3 on Tensile Strength . . . 368
- *Study of the Wrought Alloys*—
  - Procedure adopted 369
  - Behaviour of the Alloys on Rolling— 369
    - Speed of Rolling and Rate of Reduction 369
    - Possibilities of Rolling Higher Zinc Alloys . . . 370
    - Rolling Temperatures, Measurement of 370
  - Behaviour of the Alloys on Cold-Drawing 371
  - ,, ,, ,, ,, ,, Rolling into Sheets 371
  - Tensile Tests on Rolled and Drawn Material—
    - Bars Hot-Rolled to $1\frac{1}{4}$-inch diameter 372
    - ,, ,, ,, ,, $\frac{7}{8}$-inch diameter 373

PAGE
"Specific Tenacity" of Rolled Bars 377
Discussion of Results of Tests on 1¼-inch and ⅞-inch Hot-Rolled Bars 379
Bars Hot-Rolled to ½-inch diameter 379
Effect of "Additional Work" on Tensile Strength . . . 381
Effect of Work on the Alloys 382

Tensile Tests on Annealed Material—

Bars Hot-Rolled to ⅞-inch diameter after Annealing . . 383
" " " " ½-inch diameter " " . . 384
" Cold-Drawn to $\frac{13}{16}$-inch diameter " " . . 385
Comparison of Tests on Annealed Material 386
Bars Cold-Drawn to $\frac{13}{16}$-inch diameter 388
" Drawn with Annealing to $\frac{13}{16}$-inch diameter . . 389
Discussion of Results of Tests on Drawn Material . . 387–90
Microstructure of Rolled and Drawn Bars 390–93
Wire Cold-Drawn to 0·1285-inch diameter . . . 394
Do. after Annealing 395
Discussion of Results of Tests on Wire 393
Sheet Rolled to 0·13-inch Thick 397
Do. after Annealing 397
Sheet Rolled to 0·07-inch Thick 398
Do. after Annealing 398
Discussion of Results on Sheet 396

Summary of Tensile Tests—

Alloy No. 5 401
" " 9 401
" " 11 402
" " 13 402
" " 15 403
" " 16 404
" " 17 404
" " 19 405
" " 20 406
" " 26 407
Further Study of the Alloys— 407

Tensile Tests at High Temperatures—

Alloy No. 9 408
" " 11 409
" " 13 409
" " 15 410
" " 17 410

PAGE
Alloy No. 19 . . . 411
" " 20 . . . 411
" " 25 . . . 412
" " 26 . . . 412
Discussion of Results of Tests at High Temperatures . . . 408–16

Elastic Properties of the Alloys—

Determination of *Elastic Modulus* and *Elastic Limit*—

(a) Bars Hot-Rolled to $\frac{7}{8}$-inch diameter . . . 417
(b) " Cold-Drawn to $\frac{13}{16}$-inch diameter . . . 419
Autographic Stress-Strain Diagrams . . . 420
Comparison of 8-inch and 2-inch Specimens as regards Yield-Point, Ultimate Stress, etc. . . . 421
Torsion Tests on $1\frac{1}{4}$-inch Hot-Rolled Bars . . . 422
Comparison of Maximum Stresses found in Tension and in Torsion . . . 424
Hardness Numbers—Brinell and Scleroscope . . . 425
Compression Tests on Bars Hot-Rolled to $\frac{7}{8}$-inch diameter . . . 427

Dynamic Tests—

Alternating-Stress Tests . . . 429
Comparison of Elastic Limits and Yield-Points . . . 430
Alternate-Bending Impact Tests . . . 431
Repeated " " " . . . 432
Single-Blow Impact Tests (Izod) . . . 433
Professor Arnold's Alternate-Bending Tests . . . 434–5
Corrosion Tests on Sand- and Chill-Castings . . . 438

Appendix—

The Properties of a Ternary Alloy of Aluminium with Zinc and Copper . . . 441
Summary of Tensile Tests . . . 442–3
Compression Test . . . 444
Dynamic Tests— . . . 444
Alternating-Stress Test . . . 444
Repeated-Bending Impact . . . 444
Single-Blow Impact (Izod) . . . 444
Professor Arnold's Test . . . 444

General Introduction.—The Ninth Report to the Alloys Research Committee contained an account of the influence of manganese upon the alloys of copper and aluminium; the consideration of manganese was regarded as the first step in a general investigation of the ternary alloys of copper and aluminium with other metals, and the Alloys Research Committee decided that the next step in this investigation should deal with the effect of zinc. As it had been found, however, that the previous Reports dealing with the useful alloys lying at both ends of the copper-aluminium series were undesirably bulky, it was decided in the first place to confine the investigations to alloys consisting principally of aluminium, which may be conveniently grouped under the term "light alloys."

Before the systematic study of the ternary alloys of aluminium, copper and zinc could be undertaken it was, however, necessary to investigate the new base-line of this system, namely, the alloys of aluminium and zinc. In practice the investigation of the binary alloys and of the ternary alloys derivable from them has been carried on side by side, but the well-known difficulty which arises in all investigations of ternary alloys from the large number of combinations which have to be studied has made it desirable to publish the results of the investigation of the binary alloys without waiting for the completion of the study of the ternary system. The present Report, therefore, deals principally with the constitution and properties of the binary alloys of aluminium and zinc. At the same time the investigation of the ternary system has already been carried to a considerable extent and has revealed the existence of a group of alloys which promise to be of considerable practical value. While, therefore, it is impossible to publish a systematic report on the ternary system at the present stage, an Appendix has been added (page 441) to this Report in which some of the more remarkable results already obtained for certain of the ternary alloys are stated.

The alloys of aluminium and zinc have been the subject of a considerable number of experimental investigations. As regards their constitution they have been studied by Heycock and Neville,* Shepherd,† Ewen and Turner,‡ and D. V. Plumbridge,§ ‖ while as regards some of their mechanical properties important papers have been published by C. R. Carpenter,¶ W. D. Bancroft,** Ewen and Turner and M. Portevin.†† It is not proposed to give an account of these Papers here, but the results obtained by the various authors mentioned will be referred to and discussed in detail wherever they are comparable with those obtained in the present investigation.

From the point of view of practical use, the aluminium-zinc alloys have received considerable attention. For casting purposes the fact that an addition of zinc to aluminium facilitates the production of sound castings is widely recognized; at the same time, these alloys are credited with undesirable properties in two important directions. The first of these is the tendency which they are said to possess to crack in cooling, particularly if the castings are of a shape liable to that form of defect. Further, the alloys are generally regarded as being liable to rapid corrosion, and actual examples of such corrosion have come under the notice of the present authors in the case of industrially prepared alloys. The experience of the present authors, however, in dealing with these alloys does not confirm these widely held views of their properties; the authors have had no difficulty in avoiding the cracking of castings which is said to be due to the tenderness of these alloys when hot. As regards corrosion the experiments and tests described below indicate that the alloys as prepared by the authors are by no means liable to the severe and excessive corrosion which the general reputation of the alloys would lead one to anticipate. The authors supposed—and experiment has justified the supposition—that the rapid corrosion (particularly in moist air) of many commercial samples of aluminium-zinc alloys is due to the presence of impurities derived from the spelter employed in their manufacture. The authors' alloys, prepared from pure zinc, behaved in a much more satisfactory manner.

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* Heycock and Neville, "The Freezing Points of Alloys containing Zinc and another Metal," Journal, Chemical Society, vol. 71, 1897, page 389.

† Shepherd, "Aluminium Zinc Alloys," Journal of Physical Chemistry, 1905, 9, page 504.

‡ Ewen and Turner, "Shrinkage of the Antimony-Lead Alloys, etc.," Journal, Institute of Metals, 1910, vol. iv, page 128.

§ D. V. Plumbridge. Dissertation at the University of Munich, 1911.

‖ A brief preliminary account of some of the results of the present investigation has been given in the Annual Reports of the National Physical Laboratory for 1909 and 1910, and in a lecture by W. Rosenhain, at the Royal Institution in June 1910.

¶ C. R. Carpenter. Amer. Soc. of Mechanical Engineers, June 1898.

** W. D. Bancroft. *The Mechanical Engineer*, 1910, 25, pages 329–330.

†† Portevin. *Revue de Metallurgie*, 1911.

With regard to the mechanical properties of the aluminium-zinc alloys, the statement is sometimes found that they are particularly weak under the action of vibratory stresses and of shock. Here again the results of the present Research do not confirm this previously held view; the exhaustive tests under shock and alternating stresses described in this Report clearly show that these alloys are not abnormally weak in this respect, and that in effect they exhibit properties in these circumstances which are in normal correspondence with their general mechanical behaviour.

As regards the general mechanical properties of the aluminium-zinc alloys, the outstanding result of the present Research is perhaps to be found in the very large effect produced upon them by hot work. It has been found possible to roll out into bars and even to draw into wire an alloy containing as much as 25 per cent. of zinc in spite of the fact that this same alloy in the sand-cast condition shows no perceptible ductility. This alloy attains its maximum tensile strength when in the condition of rolled bar $1\frac{1}{4}$ inches in diameter, the maximum stress being 27·5 tons per square inch. It is very interesting to find that rolling down the same alloy to $\frac{7}{8}$-inch diameter while hot, so far from improving the properties of the material, brings about a reduction in the tensile strength of several tons per square inch, and similar phenomena are met with throughout the whole series of alloys. It may be added here that by the addition of a small percentage of copper to these aluminium-zinc alloys, as indicated in the Appendix to the present Report, the tensile strength of the hot-rolled material may be raised to 32 tons per square inch while retaining a reasonable degree of ductility. In the form of wire the maximum tensile strength obtained is 34 tons per square inch. The specific gravity of alloys having these high tensile strengths lies in the neighbourhood of 3·2, so that they may still fairly be regarded as light alloys; in comparison with other light high-tensile alloys containing magnesium, the present series have the advantage that no special heat treatment or quenching is required to develop their special properties.

Both the binary and ternary alloys just referred to differ in one important respect from the majority of non-ferrous alloys by the fact that in the rolled condition they exhibit a definite and well-marked yield-point, their behaviour in the testing-machine showing the sudden dropping of the beam which is familiar in the testing of mild steel. This behaviour may perhaps justify greater confidence in the properties of these alloys than that which engineers usually repose in materials having a gradual indefinite yield.

If the results of the present investigation are viewed in the light of current practice in the application of aluminium-zinc alloys, the most important point is that the alloys richer in zinc, namely, those containing from 15 to 25 per cent. of zinc (with or without the addition of copper), are deserving of much closer attention and of more widespread use as compared with the lower alloys, containing less than 15 per cent. of zinc, which are much more widely used in present practice. If dynamic as well as tensile tests are taken into consideration, the outcome of the present Report is to show that the alloy containing 20 per cent. of zinc is the most generally useful of the simple binary alloys.

In this brief notice of the outstanding results of the investigation mention must now be made of what is probably the most serious defect of this group of alloys, namely, their great sensitiveness to rise of temperature in relation to their tensile strength. Thus the alloy containing 25 per cent. of zinc, whose tensile strength at the ordinary temperature is 27·5 tons per square inch, at a temperature of 100° C. has a tensile strength of only 18·5 tons per square inch, and the rapidity of this drop in strength with rising temperature increases as the temperature is further raised. When very hot the alloys are accordingly very weak, but while they are brittle to shock and cannot therefore be forged at temperatures much above 400° C. (752° F.), in the testing machine they still exhibit an exceptional amount of ductility. Thus it is possible to roll into bars alloys which are brittle in the cast state, but an accurate control of the rolling temperature is an essential condition of success.

Summary of the Principal Results.

The principal results obtained in the investigations described in the present (Tenth) Report to the Alloys Research Committee are briefly summarized as follows :—

(1) *The Constitution of the Alloys.*—This is only briefly dealt with in the Report, since a full account of the metallographic study of the aluminium-zinc system has already been published elsewhere. The new equilibrium diagram arrived at by the authors is reproduced, showing the occurrence of reactions and the formation of a definite compound (Al_2Zn_3) whose existence had not previously been established. From the equilibrium diagram it appears that all the alloys containing more than 40 per cent. of zinc undergo transformation at a temperature of 256° C. (493° F.). As regards the alloys at and near the aluminium end of the series, the new equilibrium diagram establishes their "solidus curve" or temperature of complete solidification, and also exhibits certain minor transformations which, although shown not to be due to a change in the pure aluminium-zinc system, always occur in commercial alloys at temperatures near their melting-point. The alloys containing less than 40 per cent. of zinc are shown to be simple homogeneous solid solutions, although it is possible that the inversion at 256° C. also occurs at this end of the series.

When cast in chill moulds, the microstructure of these alloys exhibits the sharply "cored" structure usually found in rapidly cooled solid solutions having a long range of solidification. In sand-castings this coring is less sharply defined and the whole microstructure is on a larger scale. The "cores" are entirely removed by prolonged annealing at such a temperature as 400° C. (752° F.), but they are removed rapidly and completely by the rolling process. Photomicrographs of the hot-rolled alloys, especially after annealing, containing up to 25 per cent. of zinc exhibit the typical polyhedral structure of a perfectly homogeneous solid solution, although the scale of the crystals varies considerably according to the exact mode of treatment which the material has undergone. Photomicrographs of sand- and chill- castings of the whole range of binary alloys are given, together with some additional photographs of specially annealed and quenched specimens illustrating the typical features of the constitution of the system. Photomicrographs of typical examples of the structures of the rolled and drawn alloys are also given.

The Study of the Cast Alloys.—Tensile tests on sand- and chill-castings of a series of alloys covering the entire range of the binary system are given, both in tabular and graphic form. The tensile strength of sand-castings shows a steady increase up to a concentration of 50 per cent. of zinc, when an ultimate stress of 18·7 tons per square inch is reached; there is then a slight fall of strength with further increase of zinc-content, followed by a rise to a second maximum near 75 per cent. of zinc, a concentration which corresponds approximately to the composition of the compound Al_2Zn_3. The highest ultimate stress reached is 18·9 tons per square inch. The table and curve representing the results of tests on chill-castings is somewhat different in type, three maxima being observed, namely, the first at 30 per cent. of zinc with an ultimate stress of 17·9 tons per square inch, the second at 50 per cent. with 21·6 tons per square inch, and the third at 75 per cent. with 20·1 tons per square inch. The yield-points for both sand- and chill- castings are recorded as observed, but the observations were found to be somewhat uncertain in the case of the cast alloys.

In discussing the results of tensile tests on the present series of alloys the authors have used the term "Specific Tenacity," to denote a quantity which is proportional to the tensile strength and inversely to the specific gravity; this has been calculated by dividing the ultimate stress of a given alloy in tons per square inch by the weight of a cubic inch in pounds. The quotient is the breaking load in tons of a bar of the material whose cross-section is such as to make the weight of the bar one pound per inch length. From the point of view of tensile strength alone this figure may be regarded as representing the value of any structural material, and allows of comparisons on a correct basis between materials of widely different specific gravity, such as these light alloys and steel. In the cast alloys the specific tenacity is found to reach its maximum for both sand- and chill- castings in an alloy containing approximately 26 per cent. of zinc. The value attained is just over 150, as compared with a maximum value of 126 reached by the light alloys described in the Ninth Report. In the light alloys of aluminium with copper alone the specific tenacity of castings does not exceed a value of 99.

Compression tests on a number of chill- and sand- castings of the alloys, including some of higher zinc-content, have been made. These tests show that in general terms the behaviour of the castings under compression is approximately proportional to their behaviour under tension. The highest yield-point under compression was obtained with alloy No. 55 in the chill cast condition, giving a stress of 22·96 tons per square inch. It is curious to find, however, that the chill-castings are decidedly inferior to the sand-castings until a zinc-content of about 50 per cent. is passed.

The question of the possible "ageing" or even gradual spontaneous disintegration of the aluminium-zinc alloys has also been studied in connection with the sand-cast material, tensile tests on some of the alloys being repeated on specimens which had been kept for over fifteen months, but no signs of any change were observed.

The Study of the Wrought Alloys.—Billets of the alloys containing up to and including 26 per cent. of zinc were cast at the Laboratory and were rolled and drawn to various sizes, including wire and sheet, at the Milton Works of the British Aluminium Company. Hot-rolling was found possible with all these alloys, but not with an alloy containing 30 per cent. of zinc.

Tensile tests on a representative series of alloys lying between the limits of composition just named were made on material in the form of (1) bars hot-rolled to $1\frac{1}{4}$-inch diameter, (2) bars hot-rolled to $\frac{7}{8}$-inch diameter, (3) bars hot-rolled to $\frac{1}{2}$-inch diameter, (4) bars cold-drawn to $\frac{13}{16}$-inch diameter, (5) bars drawn with annealing to $\frac{13}{16}$-inch diameter, (6) cold-drawn wire 0·1285-inch diameter, and (7) sheet of 0·14 and 0·07-inch thickness. In addition, the material in the form of $\frac{7}{8}$-inch bars hot-rolled, $\frac{13}{16}$-inch cold drawn, hot-rolled $\frac{1}{2}$-inch, and wire, as well as sheet of both thicknesses, was also tested after annealing for one hour at 400° C. (752° F.). The tensile tests on all the hot-worked material gave very uniform and consistent results which can generally be represented by reasonably smooth curves when the data are plotted against zinc-content. The yield-points in these tests, as contrasted with those on castings, are well-defined and as regular as the results for ultimate stress.

In the form of $1\frac{1}{4}$-inch hot-rolled bars, the alloy No. 26 attains a tensile strength of 27 tons per square inch, with a yield-point of 25 tons per square inch and an elongation of 16·5 per cent. on 2 inches. Both the tensile tests on $1\frac{1}{4}$ and on $\frac{7}{8}$-inch hot-rolled bars give curves of ultimate stress plotted against zinc-content which are very similar to one another, but it is a striking feature of these alloys that the curve for the smaller section lies above that for the larger only up to a zinc-content of about 12 per cent.; above that concentration the $1\frac{1}{4}$-inch bars give higher ultimate stresses than the $\frac{7}{8}$-inch bars. The results of tests on still smaller sizes of material, even including the hard-drawn wire, show corresponding results, although the crossing-point of the respective curves differs from one size of material to another. The general conclusion is demonstrated that the beneficial effect of "work" on these alloys diminishes steadily with increasing zinc-content, until the 25 and 26 per cent. alloys are reached in which we find that the highest ultimate stress is always given by the $1\frac{1}{4}$-inch hot-rolled bars. These alloys, richer in zinc, therefore, present the unusual property that cold-drawing a bar from $1\frac{1}{4}$-inch to $\frac{13}{16}$-inch diameter, although it raises both yield-point and elastic limit and lowers elongation and reduction of area, actually *reduces* the ultimate stress.

The condition (excluding wire) of highest tensile strength, together with the yield-stress and elongation corresponding to that condition, are given for a series of typical alloys in the following summary Table :—

TABLE 1.

No. of the Alloy (also per cent. Zn).	Condition for Highest Ultimate Stress.	Ultimate Stress.	Yield-Point.	Elongation on 2 inches.
		Tons per square inch.	Tons per square inch.	Per cent.
5	$\frac{7}{8}$-inch hot-rolled bar	8·94	7·4	26
9	$\frac{1}{2}$-inch hot-rolled bar	11·17	6·98	38*
11	$\frac{1}{2}$-inch hot-rolled bar	13·78	9·42	35*
13	$\frac{13}{16}$-inch cold-drawn bar	14·73	12·80	19·5
17	$1\frac{1}{4}$-inch hot-rolled bar	19·85	13·20	22
20	$1\frac{1}{4}$-inch hot-rolled bar	22·64	17·3	20·5
26	$1\frac{1}{4}$-inch hot-rolled bar	27·09	25·00	16·5

* On 1 inch.

The tensile tests on annealed material were undertaken principally to ascertain whether the peculiar effects of "work" mentioned above persisted after annealing, and the results are discussed with reference to the resulting microstructures. It was found that the "hot-rolled" materials exhibited a considerable amount of deformation in their constituent crystals and that this deformation was entirely removed by annealing, although the scale of the resulting structure differed widely according to the treatment which each specimen had received. In general terms it was found that the tensile strength of the annealed materials was not strictly proportional to crystal size, but that the more severely worked material always exhibited better results after annealing than less severely treated metal. The highest ultimate stress in annealed material of the present series of alloys was obtained from alloy No. 20 in the form of annealed cold-drawn wire, the value being 21·1 tons per square inch, but it must be noted that the higher alloys of the series (Nos. 25 and 26) were not included in all the tests on annealed material.

The tests on wire and sheet gave results which have already been referred to in connection with the effect of work and of annealing. Sheets were rolled from alloys Nos. 15 and 20; the former rolled well, but the latter cracked somewhat at the edges. The tensile tests show considerable variations as regards yield-points between longitudinal and transverse tests, although these are obliterated to a considerable extent after annealing. The yield-stresses, however, gave very erratic results, and this is probably to be ascribed to slight surface cracking of the metal. In the cold-rolled condition, alloy No. 20, in the form of sheet 0·07 inch thick, gives an ultimate stress of 23 tons per square inch, but there is little or no elongation in this condition. After annealing the ultimate stress falls to 18 tons per square inch, but the elongation reaches 10 per cent. on a longitudinal and 6·25 per cent. on a transverse test.

As regards the tests on the alloys in the form of wire, it was found possible to obtain even alloys Nos. 25 and 26 in this form, but the results given by these were disappointing, since they were lower than the tests obtained with $1\frac{1}{4}$-inch hot-rolled bars. In the annealed condition, however, these wires give results which appear to be promising; thus No. 19 gives an ultimate stress of 21 tons per square inch with 17·7 per cent. of elongation. It is interesting to note that the tests on annealed wire exhibit a well-defined maximum in tensile strength at or near a concentration of 20 per cent. of zinc.

Tensile tests at high temperatures were made on a series of the alloys in order to ascertain the effect of zinc-content on the rate of loss of strength of these alloys with increasing temperature. Most of the alloys were tested up to 200° C. (392° F.), but in two cases considerably higher temperatures were employed (up to 595° C.). In every case it is found that there is a rapid fall in the yield-point and ultimate stress with rising temperature, even 50° C. producing a marked effect. The rate of loss of strength varies according to the composition of the alloy; thus at 100° C. the alloys containing up to 13 per cent. of zinc have lost about 36 per cent. of their tensile strength at the ordinary temperature; the alloys containing from 15 to 17 per cent. show a loss of 44 to 52 per cent., but this figure again diminishes to 26 per cent. for alloy No. 26. These relative rates of loss are confirmed at higher temperatures. At still higher temperatures the strength of the alloys becomes exceedingly small, but they exhibit a remarkable degree of ductility as measured by elongation and reduction of area; the latter in some cases is so great that the fracture is drawn down to a sharp point, while the elongation in one instance reached 133 per cent. Forging tests, however, show that this extreme ductility exists only under "static" loads, and that the alloys which draw out to fine points in the testing machine are broken into small fragments if struck sharply with a hammer at the same temperature.

The elastic properties of the alloys have been determined both for the hot-rolled and cold-drawn materials. They exhibit a satisfactory elastic behaviour and show well-defined elastic limits, which increase regularly with the zinc-content and consistently with the ordinary yield-point determinations. The elastic moduli of all the alloys are almost identical, lying near the value 9×10^6, a low value which may prove a disadvantage for certain possible uses of the alloys.

Autographic stress-strain diagrams have been taken from 8-inch specimens; the diagrams show well-defined yield-points and they also exhibit the stepped appearance which is typical of the mode of plastic extension of many non-ferrous materials. The comparison of the results of these tests on 8-inch test-pieces with those made on the standard 2-inch specimens shows that the two series of tests are in good agreement. Apart from a somewhat low result given by the 8-inch test-piece of alloy No. 5, the differences between the extensions are not abnormal. The ultimate stresses agree remarkably well, the values given by the 8-inch specimens being in two cases slightly higher. There is rather more divergence in the case of the yield-points, the 8-inch specimens again giving higher results.

Torsion tests have been carried out on specimens cut from the alloys in the form of 1¼-inch hot-rolled bars; comparison of the results with those of tensile tests shows that the torsional strength, although it increases considerably with increase of zinc-content, yet does not increase as rapidly as the tensile strength. The ratio of the maximum stresses under the two forms of test falls from 1·10 for alloy No. 9 to 0·76 for alloy No. 25.

The hardness numbers of the alloys, again in the form of 1¼-inch hot-rolled bar, have been determined by the Brinell method under loads of 1,000 and 3,000 kg. respectively and by the Shore scleroscope. The proportionality between the hardness numbers and tensile strength is found in these alloys to be only of a general kind, the shapes of the respective curves being notably different.

Compression tests have also been made on the wrought alloys. The results are in strict conformity with those of tensile tests, although the compression yield-stresses are always slightly higher than those found in tension.

Dynamic tests have been carried out on the alloys both with the machines designed for that purpose at the National Physical Laboratory under the direction of Dr. T. E. Stanton, and also by the kindness of Professor J. O. Arnold at the University of Sheffield. The tests made at Teddington include direct alternations of stress, repeated-bending impact and single-blow impact.

The tests in alternations of direct stress give a series of results for the safe range of alternating stresses for the alloys, and this curve lies considerably below that of the static elastic limits.

These ranges, although low when compared with the ordinary tensile test results, yet indicate a very decided advance on other light alloys which have been described in the Ninth Report. The best of those alloys (of aluminium with copper and manganese) showed a safe range of 9·4 tons per square inch, while the best of the present series has a range of 12·0 tons per square inch.

Alternate-bending impact tests were made with a weight of tup of 4·71 lb. and heights of fall of 1·0 inch and 0·71 inch respectively. Both sets of tests give curves of very similar shape which show that after 15 per cent. of zinc the resistance to this test is strictly proportional to the zinc-content of the alloy. Of the present alloys, No. 9 shows a resistance practically equal to that found in the best of the light alloys described in the Ninth Report (about 600 blows with a fall of 0·71 inch), while the best alloy of the present series (No. 25) required 3,400 blows for fracture. This power of resisting repeated impact is particularly noteworthy in view of the fact that the aluminium-zinc alloys are frequently spoken of as being weak under shock.

Single-blow impact tests, made on the Izod machine, show that the work absorbed by fracture reaches a maximum for a zinc-content lying between 15 and 20 per cent. This is in accordance with the fact that such tests are affected by both tensile strength and ductility, so that the increased tensile strength of the alloys containing more than 20 per cent. of zinc is more than outweighed by their lower ductility so far as this test is concerned. As compared with the light alloys previously studied, the present series are decidedly superior, although the difference is not so marked as under some of the other tests.

Under Professor Arnold's alternate-bending test, the alloys give remarkably uniform results, but the curve of number of alternations endured falls rapidly with increase of zinc. Professor Arnold remarks that the resistance of these alloys to his test varies from $\frac{1}{8}$ to $\frac{1}{4}$ that of heat-treated best mild structural steel. It is interesting to note, in comparing the results of the three last-mentioned forms of dynamic test, that the curves representing their results are closely related to the curves of ultimate stress and elongation or reduction of area as shown by tensile tests. Thus the repeated-bending impact tests give a curve which is closely proportional to that of ultimate stresses, while the results of Professor Arnold's tests are proportionate to the ductilities of the alloys as shown by elongation or reduction of area. The single-blow impact tests, on the other hand, appear to be proportional to the sum of these two properties.

In view of the results of all the mechanical tests the authors arrive at the conclusion that an alloy containing about 20 per cent. of zinc probably represents the best combination of properties obtainable in the simple binary aluminium-zinc series.

Corrosion tests on specimens of these alloys exposed to the sea have been carried out for a period of over 500 days, and the results show that the rate of loss of weight under such exposure increases with increasing zinc-content. The actual rate of loss, however, is not as great as might have been anticipated, varying, when allowance for the difference of density is made, from 1½ times that of Naval Brass to 1½ times that of Muntz Metal. The authors, however, regard their corrosion tests as purely preliminary, since the alloys were used in the cast state, while subsequent study suggests that annealed material would show considerably less corrosion. The method of measuring corrosion by loss of weight is also regarded as inadequate for the study of these alloys, and further corrosion tests are being undertaken.

A general feature of some importance in connection with all the alloys described in the present Report, and particularly with those containing from 10 to 30 per cent. of zinc, is the great facility with which they can be worked by machine tools of all descriptions, in most cases without the use of any lubricant. Turnings of exceptional length and strength have been obtained from several of these alloys. The machined surfaces retain their brightness in the air of the laboratory for many months without protection of any kind.

Attention is directed to the Appendix (page 441) in which the authors give a preliminary account of the properties of a ternary alloy of aluminium with zinc and copper (alloy No. 25/3) containing approximately 25 per cent. of zinc and 3 per cent. of copper. This alloy, which can be rolled hot, although some special care is required in dealing with it, gives remarkable results under mechanical tests. An ultimate stress of 34 tons per square inch has been attained with this material, while its resistance to repeated-bending impact is over 4,500 blows, as compared with 3,400 of the best of the binary alloys. Tabulated results of tests made on this alloy are given, but a fuller discussion of its properties is postponed until a systematic study of these ternary alloys has been completed.

Main Report.

Plan of Research.—The general plan followed in the present investigation is very similar to that adopted in the Eighth and Ninth Reports to the Alloys Research Committee, but variations have been introduced where special features of the present alloys appear to demand investigation. The work may be conveniently grouped under three headings: namely, (1) the study of the constitution of the alloys; (2) the study of the properties of sand- and chill-castings; and (3) the study of the rolled drawn and cold-worked material. In addition to this systematic study a number of special experiments were made to investigate special questions. Since the knowledge of the constitution of the alloys is of fundamental importance for an understanding of their general properties that portion of the research dealing with the constitution of the alloys will be dealt with first.

The Constitution of the Alloys.—At the outset of the present research the authors hoped that an investigation of the constitution and equilibrium diagram of the aluminium-zinc series would be unnecessary, since an equilibrium diagram which had received general acceptance had been published by Shepherd.* They thought it advisable, however, to take a few cooling-curves of typical members of the series in order to verify Shepherd's results,

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* "Aluminium-Zinc Alloys," Journal of Physical Chemistry, 1905, 9, page 504.

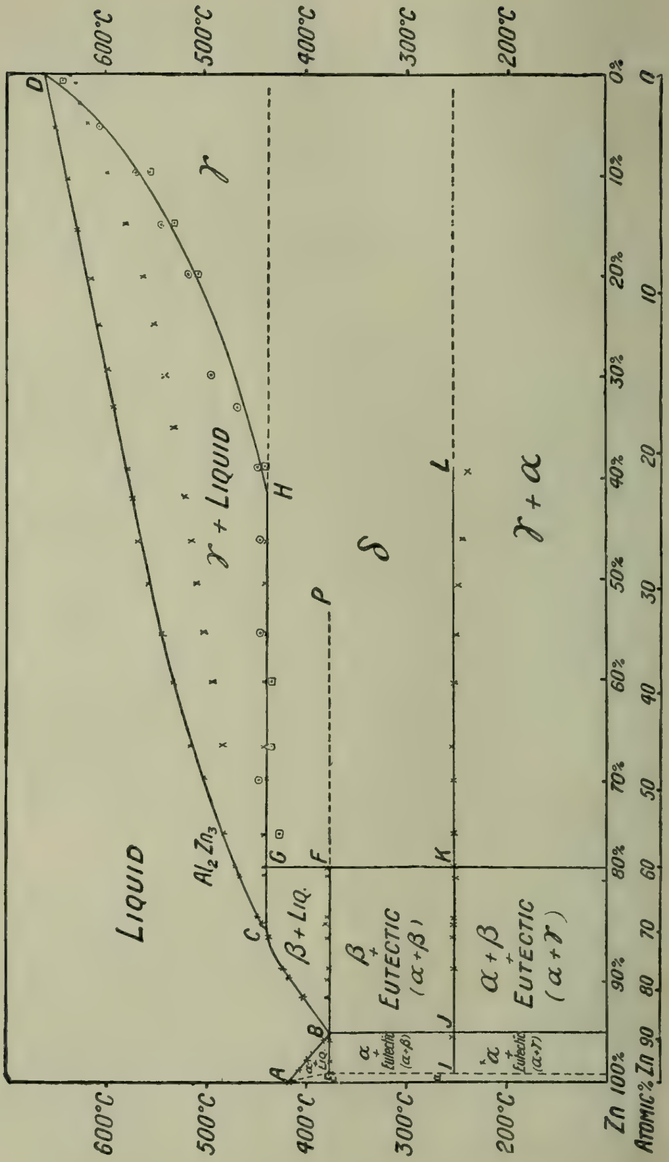

FIG. 1.—*Equilibrium Diagram of the Aluminium-Zinc Alloys.*

and these observations at once made it evident that a complete re-investigation of the series from this point of view would be necessary. This was accordingly undertaken and a very considerable amount of experimental work was necessarily devoted to it. The net result of this work is represented by the equilibrium diagram given in Fig. 1. The authors felt, however, that a complete account of this branch of their investigation, together with a full discussion of a number of points of theoretical interest raised by their results, would occupy an unduly large space in the present Report. With the consent of the Alloys Research Committee they therefore decided to embody a detailed account of their work on the constitution of the alloys in a separate Paper, which was communicated, in February 1911, to the Royal Society, by whom it has since been published in the Philosophical Transactions.* This accordingly renders it unnecessary to give a full detailed account of the metallographic study of the alloys in the present Report, and this section is devoted principally to a statement of the conclusions reached by the authors in regard to the constitution of the alloys, the experimental evidence on which those conclusions are based being described in the briefest outline only.

In the equilibrium diagram of the alloys given in Fig. 1 the liquidus is represented by the line ABCD. This differs from the liquidus as given by Shepherd only by the insertion of a small break at C. The solidus, however, which has been determined by the present authors with great care by means of a large number of quenching experiments, differs materially from that indicated by Shepherd. On the diagram, Fig. 1, the solidus is represented by the lines AE, EB, BF, FG, GH, HD. The point B on the line EBF, representing the aluminium-zinc eutectic alloy, is in agreement with Shepherd's results, except that the latter continues the eutectic line considerably to the right of the point F. The authors have, however, shown that the existence of eutectic to the right of the point F (about 78 per cent. of zinc) is meta-stable, and that this eutectic disappears entirely if the reaction along the line CH has been allowed to complete itself, either by sufficiently slow cooling or by annealing at or near

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* "Royal Society, Phil. Trans.," A. 211, pages 315–343.

400° C. The authors have in fact shown that along the line CH a reaction takes place between the solid crystals already present and the remaining mother liquor which results in the gradual formation of a definite aluminium-zinc compound, probably having the formula Al_2Zn_3. The composition of this compound is indicated in the diagram by the vertical line GFK which terminates the line of stable eutectic formation at the point F. To the left of the line GFK the reaction along the line CGH produces crystals of the compound suspended in the mother liquor which ultimately freezes, as a eutectic of zinc and the compound, along the line BF. A photomicrograph of one of these crystals embedded in the eutectic is shown in Fig. 2, Plate 9.

The six-rayed character of these dendritic crystals is a striking characteristic of this compound of aluminium and zinc, which differs materially in this respect from most other metallic bodies. To the right of the line GFK there is no residue of liquid after the formation of the compound, but, on the other hand, one would expect to find a residue of the solid solution (called γ in the diagram) forming a duplex structure with the compound in the region GKLH. The microscope, however, shows that the alloys in this region are completely homogeneous, so that the compound and the γ solid solution evidently form an unbroken series of solid solutions. In accordance with this result, phase-rule considerations would lead one to expect that the line GH should be curved or sloped and not strictly horizontal. The experimental evidence, however, very strongly supports the conclusion that the line is so nearly horizontal that any departure cannot be demonstrated. Similarly phase-rule considerations will again lead one to look for a curved line starting at or near the point H and indicating the saturation limit of the solid solution γ. No experimental evidence has, however, been obtained for the existence of such a line and the authors prefer to omit the line entirely, thus leaving the diagram incomplete from the strictly theoretical point of view, rather than to insert an imaginary line having no experimental justification.

The authors have further shown that the compound formed along the line CGH at a temperature of 443° C. (829° F.) undergoes decomposition accompanied by a vigorous evolution of heat at 256° C. (493° F.) along the line IJKL. In the alloys to the right of the line GFK the change brought about in the microstructure by this latter inversion is of a very striking kind. Fig. 3, Plate 9, shows the homogeneous structure of one of the alloys (77 per cent. of zinc) quenched from a temperature above the line IJKL after having been annealed at 440° C. (824° F.), in order to complete the reaction along the line CGH. The same alloy when slowly cooled to below 256° C. exhibits the duplex structure shown in Fig. 4; this structure has a striking resemblance to the pearlite of carbon steels and is one of the very few examples of such a laminated structure resulting from a decomposition occurring in a solid alloy. To the right of the line GFK this decomposition takes place in a solid solution formed of the compound Al_2Zn_3 and aluminium; the same change can, however, be traced in the crystals of the compound free from excess of aluminium embedded in eutectic, in alloys lying to the left of the line GFK. In Fig. 5 we have the microstructure of such an alloy containing 84 per cent. of zinc which has been annealed at a temperature just below that of the eutectic and has then been quenched from a temperature just above 256° C.; we see homogeneous crystals of the compound embedded in the eutectic. The same alloy allowed to cool slowly and held for a time at 256° C. in order to allow the decomposition of the compound to be completed is illustrated by Fig. 6, Plate 10, where the duplex character of the decomposed compound is clearly evident. Since the formation of the compound is a comparatively slow process and its decomposition, although not so slow, is still easily hindered by rapid cooling, the actual microstructures met with in specimens of these alloys cooled at the ordinary rate are very complex indeed. For instance, in an alloy containing 75 per cent. of zinc we find that solidification has commenced by deposition of crystals of the solid solution γ, but since these have been formed over a considerable range of temperature they exhibit the core-structure familiar in the crystals of all solid solutions having a long freezing range. On reaching the temperature of 443° C. (829° F.) these solid solution crystals become surrounded by sheaths of the compound Al_2Zn_3 and these sheaths increase in thickness as the metal cools further. Even with moderate rates of cooling the metal will reach the temperature of the dotted line FP before the whole of the residual liquid has been absorbed by the formation of the compound, and this residual liquid will then solidify in the meta-stable form of eutectic. Again, when this complex mass reaches the temperature of 256° C. the sheaths of compound surrounding the γ solid solution crystals will undergo partial decomposition. The resulting complex microstructure is illustrated in Fig. 7, Plate 10.

If the alloy lies further towards the aluminium end of the series the formation of eutectic may not occur and a slightly less complex structure will be the result; this is illustrated in Fig. 8. Finally, to the right of the point H there is no definite evidence of the occurrence of the formation of the compound, and the microstructures met with are accordingly those of a simple solid solution; with moderately rapid cooling the alloys exhibit the strongly marked core structure already referred to, but annealing or very slow cooling renders them completely homogeneous.

The complexity of the microstructure which has just been described is reflected by a corresponding complexity in the cooling curves of these alloys, some typical examples of which are reproduced in Fig. 9.

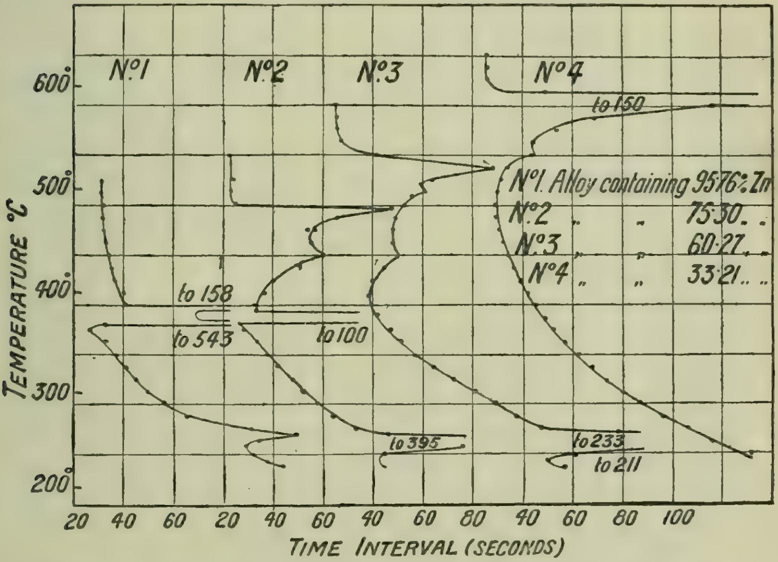
The bearing of this equilibrium diagram on the mechanical properties and thermal treatment of the aluminium-zinc alloys has now to be considered. It is seen at once that the most important light alloys of the series belong to the simple region of the diagram and that they should consist of homogeneous solid solutions, provided that the rate of cooling has been sufficiently slow or that they have been subjected to annealing or hot working accompanied by annealing.

The microstructures of the actual alloys used in the mechanical experiments are illustrated in Figs. 17–52, Plates 11–17 (cast alloys), and Figs. 64–83, Plates 18–21 (wrought material), inclusive, and it will be seen that these represent the various stages ranging from a typical cored to a completely homogeneous solid solution.

This variation accounts to a considerable extent for the wide difference in properties between chill-cast, sand-cast, and rolled specimens, if we remember that the hardness and brittleness of the alloys increase with increasing content of zinc. If we take, for instance, an alloy whose average zinc-content is 20 per cent. and cool it rapidly from fusion, we may obtain a cored structure whose inner portion may contain as little as 5 per cent. of zinc, while the outer portions of the crystals may contain 40 per cent. of zinc. In such a material the brittleness of these outer rims of the crystals would very seriously affect the ductility of the whole, but, when such a casting came to be heated prior to rolling, these large differences of concentration would rapidly diminish and with it the greater brittleness of the outer crystal zones would disappear. On the other hand, the absence of critical changes or inversions in the alloys containing less than 30 per cent. of zinc leads one to expect that thermal treatment such as annealing or quenching will

Fig. 9.

Some Typical Cooling Curves.



produce no other effects than those met with in pure metals, so soon as homogeneity of the solid solution has once been obtained.

(2) *Study of the Cast Alloys.*—The materials used for the production of the alloys throughout the present Research have been: (1) *Aluminium.* A quantity of aluminium, amply sufficient for the entire Research, was presented by the British Aluminium Co. The metal was in the form of notched bars and of the purest quality industrially manufactured. Its analysis was as follows:—

Silicon	0·17 per cent.
Iron	0·20 ,, ,,
Copper	trace.
Aluminium (by difference) . .	99·63 ,, ,,

(2) *Zinc.* A quantity of zinc, sufficient for the whole of the present Research, was presented by the Right Hon. Sir John Brunner, Bart. The metal is understood to be the product of a special process employed by Messrs. Brunner, Mond and Co., Ltd., and it is of exceptional purity. Only traces of iron and silicon could be found and the zinc-content was not less than 99·98 per cent.

Preparation of the Alloys.—In all some twenty-five alloys of the binary series were prepared, eleven of these lying between the limits of 5 and 25 per cent. of zinc. These eleven alloys, some of which are repeat meltings intended to be of the same composition, were at once made on the "larger" scale, and quantities of 20 to 25 lb. were melted and cast in the form of sand-castings, chill-castings, and rolling billets. Beyond the zinc-content of 25 per cent. there was no occasion to cast the billet, since the alloys are no longer suitable for hot rolling. For the alloys lying between 30 and 95 per cent. of zinc, therefore, smaller quantities, about 7 to 12 lb., were melted and sand- and chill- cast test-pieces were alone produced.

Melting the Alloys.—The alloys were melted in a petroleum spray Fletcher Russell furnace, in Salamander crucibles. Near the aluminium end of the series the aluminium was melted down first, and the requisite quantity of zinc was then added. The zinc dissolved very rapidly and the thoroughly fluid alloys were then vigorously stirred, skimmed, and poured. In the case of the alloys richer in zinc a previously prepared 50 per cent. alloy of aluminium and zinc was used in place of pure zinc or pure aluminium, as the case might be. It was found, however, that even the 50 per cent. alloy was not sufficiently brittle to be broken up with a hammer, so that one of the conveniences usually obtained by using such a rich alloy was not available in this case.

No attempt was made to protect the metal during fusion by a covering of any kind such as a flux, charcoal, etc. The use of charcoal was indeed tried, but the properties of the resulting castings was so much inferior to those produced in the ordinary way that the use of charcoal was definitely abandoned as being injurious to the metal. In order, however, to reduce the amount of oxidation during fusion as far as possible, care was taken to avoid all overheating of the metal, and even near the aluminium end of the series the furnace was never allowed to attain a temperature exceeding 800° C. (1,472° F.) The casting temperatures were in all cases kept as low as possible consistent with filling all the moulds. As a rule casting commenced when the metal was from 50° to 60° above its freezing point, the metal generally commencing to solidify in the crucible towards the end of the operation. There is no doubt that these alloys, like all aluminium alloys, are considerably affected by variations in the casting temperature, and with the comparatively small quantities of metal operated upon in these experiments some such variations could not be avoided. The discrepancies between duplicate results occasionally noted throughout the tests made on cast material may probably be ascribed to this cause, which usually operates by affecting the soundness of the castings.

Some difficulty was found at first in casting small chills without producing cold shuts. The alloys being poured so near their freezing point, it was found that drops or splashes striking the vertical side of the cold mould solidified instantly and these produced flaws in the finished casting; where these were found the chills in question were remelted and the casting repeated. This remelting process involved a slight change of composition and consequently analyses of both the chill- and sand-cast specimens have been made. Where remelting of the chills has not been required, differences in composition between chill- and sand-cast specimens were found to be negligible.

Generally speaking, the alloys of aluminium and zinc may be described as casting easily; the molten metal is much more fluid than pure aluminium, and provided that sufficient head is used, and that the shrinkage of the alloy is neutralized by careful following up, perfectly sound castings, even of complicated shapes, can be made. A photograph is shown on Plate 22, of two castings, one rough and the other machined, which were made with the alloy containing 25 per cent. of zinc in order to test the facility of manipulation in this respect. The castings of these alloys possess a remarkable ring when struck with a hard object.

On the photograph of the two castings just referred to, Plate 22, is also shown a remarkably long turning taken from one of the present series of alloys (in the rolled condition), the cut being taken at a high speed and entirely without a lubricant. Turnings as much as 19 feet in length as they come from the lathe have been obtained in the course of preparing the test-pieces. This behaviour is typical of the whole series, even including the alloy 25/3 referred to in the Appendix, which all lend themselves to working by machine-tools with exceptional facility.

The patterns and moulds used for the production of both sand- and chill-castings were the same as those employed in connection with the Researches described in the Eighth and Ninth Reports to the Alloys Research Committee, so that no further details need be given here.

The compositions of the cast alloys are stated in Table 2; the first column of this Table gives the numbers of the alloys, by which they will be referred to throughout the present Report; these numbers indicate as closely as possible the percentage of zinc contained in the alloys, so that for general purposes reference to the Tables of composition will be avoided. The next column of the Table gives the weights of metal used (in ounces) in the preparation of the various alloys; the next following gives the composition aimed at, while the last two columns give the results

TABLE 2.

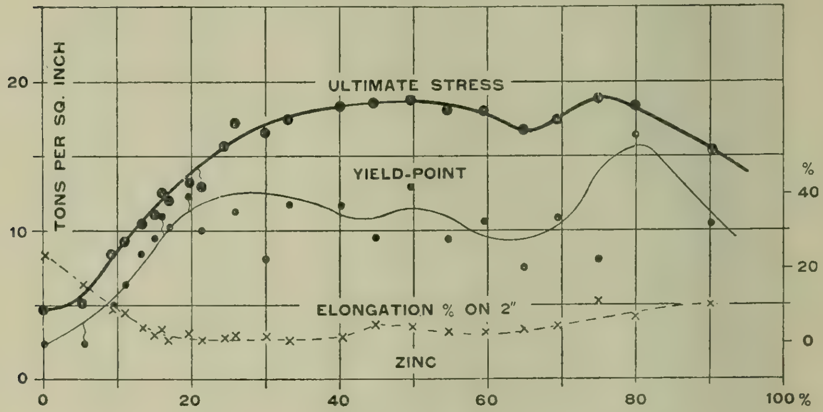
Composition of Cast Alloys.

No. of Alloy.	Weights of Metal used —in Ounces.			Composition aimed at. (Zn per cent.)	Composition found by Analysis. (Zn per cent.)	
	Al.	50 % Al-Zn.	Zn.		Chill-Casting.	Sand-Casting.
5	332·5	—	17·5	5	—	5·21
9	318·5	—	31·5	9	9·28	9·25
11	264	—	36	12	—	11·0
13	305	—	45	13	13·69	13·24
15	297·5	—	52·5	15	14·29	15·05
16	249	—	{51 (+5 lb. scrap)}	15	16·11	16·04
17	332	—	68	17	—	16·85
19	240	—	60	20	18·39	19·67
20	320	—	80	20	20·15	—
25	225	—	75	25	22·74	24·50
26	300	—	100	25	26·05	—
30	52·5	—	22·5	30	30·31	30·14
35	46·25	—	26·25	35	36·02	—
40	60	—	40	40	40·27	—
45	55	—	45	45	44·75	44·75
50	50	—	50	50	49·70	49·62
55	—	90	10	55	55·15	54·98
60	—	80	20	60	59·20	59·63
65	—	70	30	65	65·35	64·80
70	—	60	40	70	69·22	69·42
75	—	50	50	75	74·63	75·02
80	—	50	75	80	80·60	79·97
90	—	30	120	90	90·41	90·31

of analyses of both the chill-castings and the sand-castings of each alloy. It will be seen that only in two cases does the composition of the sand-castings, as found by analysis, differ by more than 0·5 per cent. from the composition aimed at, a result which indicates that loss of zinc by volatilization was to a considerable extent avoided in these meltings.

Tensile Tests on Cast Alloys: (a) Sand-Castings.—The results of tensile tests on sand-castings of the alloys are given in Table 3, while the same results are presented graphically in Fig. 10. The test-pieces employed were of the form specified by the Engineering Standards Committee and were similar in every respect to those described in connection with the Eighth and Ninth Reports.

FIG. 10.
Tensile Tests on Sand-Castings.



The figures for ultimate stress given in the Table and utilized in the diagram are in every case the higher of at least two duplicate tests. With the exception of alloy No. 26 the difference between such duplicates did not exceed 0·6 of a ton, and in the majority of cases the agreement was much closer than this. The only exception is alloy No. 26, in which the two duplicates differed by 2·3 tons. The observations for "yield-point" are much less satisfactory, and

TABLE 3.

Tensile Tests on Sand-Castings.

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 inches.
	Tons per sq. in.	Tons per sq. in.		Per cent.
5	2·7	5·20	0·52	16·0
9	5·0	8·52	0·59	9·0
11	6·4	9·41	0·68	8·0
13	8·5	10·55	0·80	4·0
15	9·6	11·14	0·86	2·0
16	11·0	12·71	0·87	3·5
17	10·2	12·13	0·84	0·7
19	12·4	13·25	0·93	2·5
20	10·0	13·07	0·77	0·7
25	none	16·26	—	1·0
26	11·2	17·32	0·65	2·2
30	8·11	16·63	0·99	1·5
35	11·7	17·37	0·67	0·5
40	11·6	18·27	0·64	1·2
45	9·5	18·51	0·51	4·7
50	13·0	18·71	0·69	4·0
55	9·5	18·0	0·53	2·7
60	10·6	17·88	0·96	2·5
65	7·5	16·86	0·44	3·5
70	10·8	17·5	0·63	4·5
75	8·0	18·90	0·42	10·7
80	16·6	18·51	0·90	7·0
85	—	—	—	—
90	10·6	15·52	0·70	10·2
95	—	—	—	—

when it is considered that for all alloys containing more than 15 per cent. of zinc the elongation is extremely small (under 4 per cent.), this is not altogether surprising. The figures tabulated in the column headed "Yield-Point" are therefore of an indefinite nature, being the means of sometimes widely divergent observations; it is evident that in these alloys, if they may be said to possess a yield-point at all, the exact load at which it occurs is not well defined. The uncertainty attached to the yield-point figures applies of course equally to the figures for the elastic ratio.

The curves of Fig. 10 representing the data of Table 3 show an interesting feature in the gradual increase of tensile strength with the addition of zinc until the first maximum is reached in the 50 per cent. alloy; there is then a slight fall down to 65 per cent., and a second more clearly defined maximum appears at 75 per cent. This latter maximum is of special interest in connection with the equilibrium diagram since it coincides approximately with the composition of the compound Al_2Zn_3 (78·37 per cent. of zinc). Although in the sand-cast alloys the rate of cooling would be too rapid to allow the complete formation of this substance, yet its presence, and particularly the presence of the duplex decomposition product referred to in Section 1, is no doubt responsible for the rise of the curve of ultimate stress and also—if we may attach any weight to it—for the rise in the curve of yield-points. At the other end of the series it is interesting to notice that the tensile strength of the alloys increases with increasing concentration of zinc in the γ solid solution, but that this rise ceases at or near 40 per cent. of zinc, corresponding approximately to the point H in the equilibrium diagram.

The tensile strength of sand-castings of aluminium-zinc alloys has already been investigated by Turner and Ewen * and more recently by Portevin.† The results obtained by these authors, although probably not strictly comparable with those of the present experiments, owing to differences of conditions and particularly to

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* See footnote to page 324.

† See footnote to page 324.

differences in the purity of the zinc employed, yet furnish an interesting comparison with the present series of tests. Their results are represented graphically in Fig. 11, in which a curve showing the results obtained by the present authors is plotted on the same scale. It will be seen that the results of both Turner and Ewen and of Portevin are throughout a little lower, but between 45 per cent. of zinc and 80 per cent. of zinc there is a very close approximation between Turner and Ewen's curve and the present results. The castings tested by Ewen and Turner were, however, annealed. It should be pointed out that while Ewen and Turner and Portevin each give nine plotted points the present authors have plotted twenty-three points, representing more than double that number of actual tests. The present authors have therefore

Fig. 11.

Tensile Strength of Al-Zn Sand-Castings.

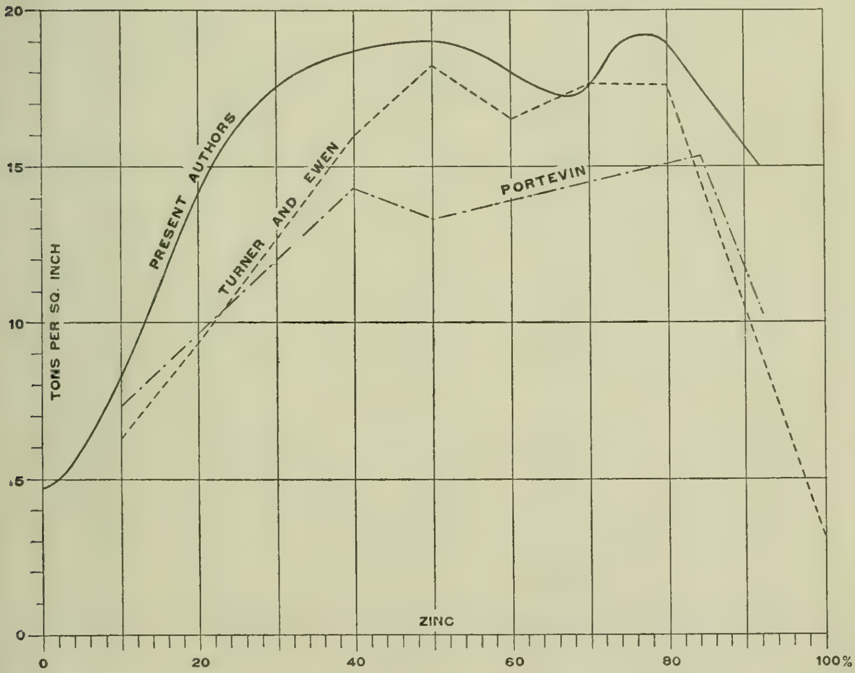


TABLE 4.

Ageing of Sand-Castings.

No. of Alloy.	Age.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
		Tons per sq. in.	Tons per sq. in.	Per cent.
9	Freshly made	5·0	8·52	9·0
	16 months	7·33	10·40	7·5
13	Freshly made	8·47	10·55	4·0
	16 months	9·29	11·80	4·0
15	Freshly made	9·55	11·14	2·0
	16 months	9·62	12·59	2·5
30	Freshly made	8·11	16·63	1·5
	10 months	12·64	17·45	1·5
35	Freshly made	11·66	17·37	0·5
	10 months	11·93	17·52	2·0
45	Freshly made	9·52	18·51	4·7
	10 months	16·64	19·14	2·0
60	Freshly made	10·62	17·88	2·5
	10 months	13·88	18·75	2·5
75	Freshly made	8·01	18·90	10·7
	10 months	17·67	19·24	9·0

TABLE 5.

Tensile Tests on Chill-Castings.

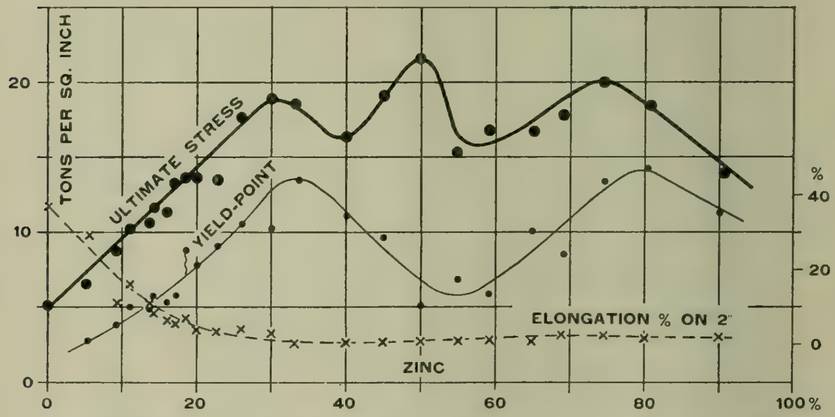
No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 inches.
	Tons per sq. in.	Tons per sq. in.		Per cent.
5	2·8	6·60	0·43	29·0
9	3·9	7·80	0·49	11·0
11	5·0	10·24	0·51	16·0
13	4·9	10·71	0·46	10·5
15	5·8	11·69	0·49	8·5
16	5·3	11·36	0·47	6·5
17	5·8	13·63	0·34	5·2
19	8·8	13·70	0·64	7·0
20	7·8	13·82	0·57	4·0
25	9·1	13·50	0·67	3·5
26	10·6	17·72	0·60	4·0
30	10·3	17·92	0·58	3·0
35	13·6	17·52	0·78	0·5
40	11·1	16·34	0·68	0·5
45	9·7	19·14	0·51	0·7
50	5·1	21·59	0·24	1·0
55	6·8	15·44	0·44	1·0
60	6·0	16·93	0·36	1·5
65	10·1	16·74	0·60	0·7
70	8·6	17·85	0·48	2·5
75	13·4	20·12	0·67	2·0
80	14·3	18·67	0·61	1·5
85	—	—	—	—
90	11·3	13·98	0·32	2·0
95	—	—	—	—

felt justified in drawing a smooth curve representing their results, while the earlier authors have been content with joining the observed points by straight lines.

Ageing Tests.—Since it has been found that certain aluminium alloys are subject to a process of gradual spontaneous disintegration, particularly in the cast state, it was thought desirable to examine sand-cast alloys of the present series at the widest possible interval of time available, with a view to detecting any signs of disintegration. Accordingly a certain number of sand-cast specimens were laid on one side when the alloys were originally made and tested, and these have been tested after an interval of fifteen months.

Fig. 12.

Tensile Tests on Chill-Castings.



The comparative results are given in Table 4 (page 352), and it will be seen that there is no sign whatever of any diminution of tensile strength, so that if these alloys are subject to any ageing process at all it must be of an extremely gradual character.

Chill-Castings.—The results of tensile tests on chill-castings of the aluminium-zinc alloys are given in Table 5 (page 353) and are represented graphically in Fig. 12. The figures for ultimate stress are again the highest of at least two duplicates. In this series there was not quite such good agreement between duplicate tests as in the case of sand-castings, particularly where the alloys containing more than 25 per cent. of zinc were concerned. For alloys containing up to 25 per cent. of zinc the differences between duplicates did not exceed 0·9 of a ton. With the more brittle alloys lying between 30 and 95 per cent. of zinc, however, discrepancies in some cases as high as 4 tons were found, so that this portion of the curves is not as well established as the corresponding curve for sand-castings. These discrepancies, however, are not sufficient materially to affect the shape of the curves given in Fig. 12 (page 354). In this case we have a first maximum of tensile strength at 30 per cent. of zinc, this alloy attaining a tensile strength of nearly 18 tons per square inch, a value which is remarkably high for an alloy of comparatively low specific gravity (3·35).

The tensile strength next falls off to 40 per cent. of zinc and then rises again to a second sharp maximum at 50 per cent., where a tensile strength of over 21 tons per square inch is attained. It will be seen that this maximum corresponds to the maximum in the curve of Fig. 10 (page 348) relating to sand-castings, but it is more marked in the present instance. Finally, there is a third maximum at 20 tons per square inch in the 75 per cent. alloy; this again corresponds with a maximum in the tests of sand-castings.

The observations of yield-points are again indefinite, and no great weight can therefore be attached to the curve of yield-point as given in Fig. 12, except that it is seen to follow the curve of ultimate stress so far as the first and last maxima are concerned, but it is curious to find that the maximum in the ultimate stress curve at 50 per cent. of zinc is entirely ignored or even reversed by the curve of yield-stresses.

The results of tensile tests on these alloys derive their chief interest from the comparatively low specific gravities of the alloys concerned. The specific gravities and some quantities derived from them may therefore be considered here, particularly since the tendency of practice to confine itself to the alloys containing less

TABLE 6.

No. of Alloy.	Specific Gravity in grammes per cubic centimetre.			
	Sand-Cast.	Chill-Cast.	Hot-Rolled.	Cold-Drawn.
5	2·737	2·783	2·800	2·800
9	2·810	2·848	2·867	2·868
13	2·914	2·910	2·944	2·940
15	2·956	2·956	2·987	2·985
17	2·973	3·017	3·029	3·035
20	3·061	3·082	3·093	3·088
26	3·176	3·208	3·241	—
30	3·283	3·352	—	—
35	3·325	3·424	—	—
40	3·414	3·627	—	—
45	3·621	3·753	—	—
50	3·906	3·920	—	—
55	3·992	4·103	—	—
60	4·290	4·123	—	—
65	4·487	4·383	—	—
70	4·707	4·768	—	—
75	5·043	5·008	—	—
80	5·458	5·380	—	—
90	6·182	6·120	—	—

than 10 per cent. of zinc is probably derived from a mistaken impression as to the effect of further additions of zinc upon the specific gravity.

TABLE 7.

No. of Alloy.	Specific Gravity in lb. per cubic foot.			
	Sand-Cast.	Chill-Cast.	Hot-Rolled.	Cold-Drawn.
5	170	173	174	174
9	175	177	178	178
13	181	181	183	183
15	184	184	186	186
17	185	188	188	189
20	190	192	192	192
26	198	200	202	—
30	204	209	—	—
35	207	213	—	—
40	212	226	—	—
45	225	234	—	—
50	243	244	—	—
55	248	255	—	—
60	267	257	—	—
65	279	273	—	—
70	293	296	—	—
75	314	312	—	—
80	340	335	—	—
90	385	381	—	—

The specific gravities of the entire series of alloys in the form of castings are given in Tables 6 and 7 and the same results are represented graphically in Figs. 13 and 14; the former figure represents the variations of specific gravity with composition throughout the entire series of alloys, while the latter gives the data for the alloys containing less than 30 per cent. of zinc on

FIG. 13.

Specific Gravity of the Cast Alloys.

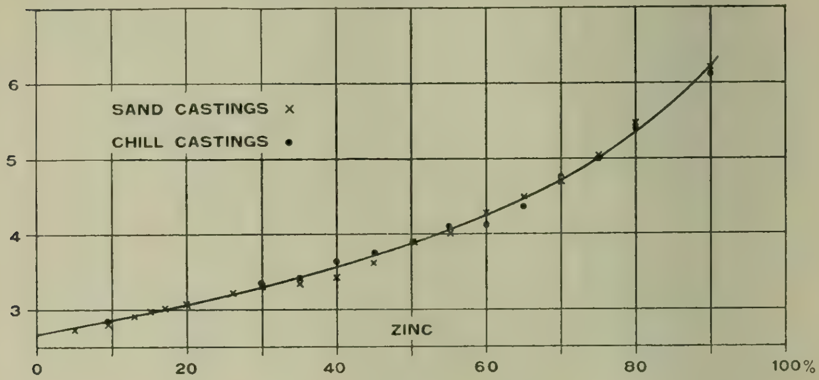
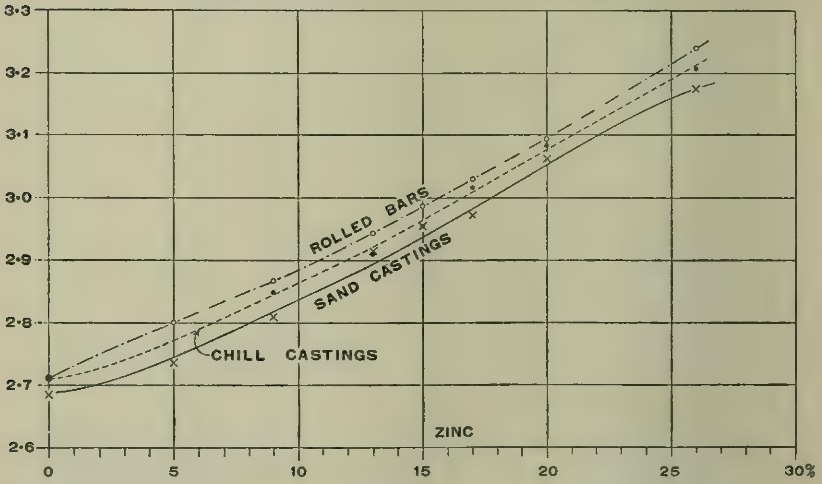


FIG. 14.

Specific Gravities of the Light Al-Zn Alloys.



a larger scale. For convenience, the specific gravities of the rolled bars of these alloys have also been inserted on this figure. On the scale of Fig. 13 it has not been found possible to draw separate curves for the sand- and chill- castings respectively, and the single curve may be regarded as representing the observations on both kinds of castings with reasonable accuracy. Yet the small differences of specific gravity between the sand- and chill-casting of each of the alloys is probably significant in connection with the constitution of the alloys. Thus up to about 50 per cent. of zinc, the chill-castings are always slightly denser than the sand-castings, and this difference is most marked in the neighbourhood of 40 per cent., where the formation of the compound Al_2Zn_3 first makes itself felt. For alloys containing more than 50 per cent. of zinc, however, this relation is reversed and the sand-castings are found to be very slightly but still definitely denser than the chill-castings. Much further investigation would, however, be required to explain these peculiarities adequately. On the larger scale of Fig. 14 separate curves have been drawn for the sand- and chill-castings, although it will be seen that in the neighbourhood of 15 per cent. of zinc the observed values for the two kinds of casting fall very close together.

By combining the results of tensile tests with the observed specific gravities of the alloys it is possible to arrive at a constant, which is of some interest as measuring the structural value of a material from the exclusive point of view of weight and tensile strength. It is, of course, to be understood that such factors as ductility or brittleness, price and other considerations, are disregarded in this calculation. If, however, these other factors may be assumed equal in two materials, their relative structural value will vary proportionately to their strength and inversely to their specific gravity. If we take ultimate stress as defining "strength," we may define the "specific tenacity" of a material as the breaking load of a bar of such cross-section that every inch length weighs one pound. The specific tenacity thus defined may be obtained by dividing the ultimate stress by the weight of a cubic inch.

The values of the specific tenacities of the present series of cast alloys are tabulated in Table 8 (page 360), where column (1) refers to sand-castings, column (2) to chill-castings, while the remaining columns refer to the wrought material obtainable in the case of the alloys near the aluminium end of the series. It will be seen that

TABLE 8.

Specific Tenacities.

$$\text{The Specific Tenacity} = \frac{\text{Ultimate Stress in Tons per square inch}}{\text{Weight of one cubic inch in lb.}}.$$

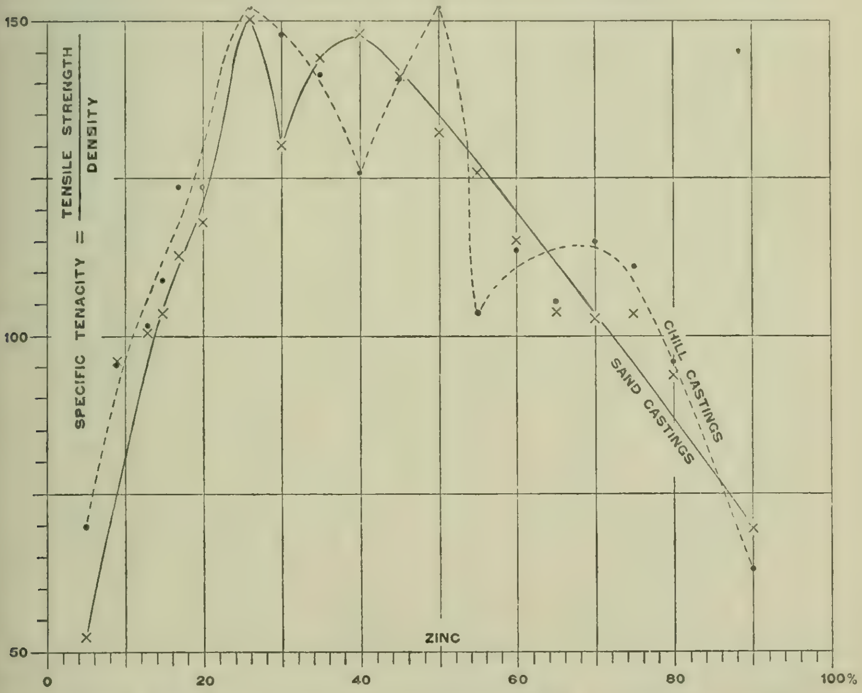
(The Specific Tenacity is the Breaking Load, in Tons, of a bar whose weight is 1 lb. per inch length.)

No. of Alloy.	Specific Tenacity.			
	Sand-Cast. (1)	Chill-Cast. (2)	Rolled to 1¼ in. (3)	Rolled to ⅞ in. (4)
5	52·5	69·9	73·8	88·2
9	91·2	95·7	90·7	100·0
13	100·6	101·7	128·3	141·1
15	103·6	109·1	151·6	153·1
17	112·8	123·6	181·1	165·1
19	—	—	—	—
20	118·2	123·6	202·3	191·2
26	150·3	152·3	231·1	203·5
30	130·3	147·9	—	—
35	144·3	141·5	—	—
40	147·9	125·7	—	—
45	141·2	141·0	—	—
50	132·4	152·3	—	—
55	125·7	103·9	—	—
60	115·3	113·6	—	—
65	103·9	105·6	—	—
70	102·8	115·0	—	—
75	103·6	111·1	—	—
80	93·7	95·9	—	—
90	69·4	63·1	—	—

the sand-castings attain their maximum specific tenacity with a zinc-content of 25 per cent., the value of the constant being 150·3. For purposes of comparison, the specific tenacities of the light alloys described in the Eighth and Ninth Reports to the Alloys Research Committee have also been calculated, and the best of these in the form of sand-castings is an alloy containing 3 per cent. of copper and 1 per cent. of manganese with a specific tenacity of 90·8.

Fig. 15.

Specific Tenacity of the Sand- and Chill-Castings.



The comparison between the sand- and chill-castings as regards specific tenacity is facilitated by Fig. 15, where the sand-castings are represented by the full and the chill-castings by the dotted curve. The highest value attained by the chill-castings is 152 in the case of alloy No. 26, this value being derived from an ultimate stress of 17·7 tons per square inch and a weight of 0·116 lb. per cubic inch. Comparison with the aluminium-copper and aluminium-copper-manganese alloys already referred to again shows the superiority of the present series, since the highest value attained by the older alloys is 126.

A comparison of the full and dotted curves of Fig. 15 shows at once that there is no systematic difference between the specific tenacities of the sand- and chill-cast material. In fact, if the variability of the specific gravities of cast metal is considered, it would almost be justifiable to draw these two curves alike. It would thus appear that in the alloys as cast, that is, before "work" has been applied to them, the specific tenacity is simply a function of chemical composition independent of the rate of cooling—that, in fact, the differences of tensile strength exhibited by sand- and chill-castings of the same alloy are simply a question of density, the greater strength of the chill-casting being accompanied by correspondingly greater density and—presumably—soundness.

Compression Tests.—These have been carried out in order to ascertain the value of these alloys for those purposes where compressive strength is of special importance; since the tensile strengths of some of these alloys are remarkably high, it became important to ascertain by actual measurement whether the compressive strength was equally or proportionately good. The tests were carried out on short cylindrical rods having a diameter of 0·564 inch and a parallel length of 2·5 inches. The ends of these test-pieces were accurately threaded to fit firmly into two large steel plates; the ends of the specimens were specially machined true and the fitting was so arranged that these end surfaces bore upon the bottoms of the holes in the steel plates. The specimens were thus in the condition of short struts fixed at both ends. The yield-points were observed by means of dividers on a length of 2 inches, a definite drop of the beam of the machine being generally observed at the same time. The load was then taken somewhat further, when finally a very well-defined collapse occurred—coincident with the visible bending of the

TABLE 9.

Compression Tests.

Chill-Castings.

No. of Alloy.	Yield-Point.	Collapsing Stress.
	Tons per sq. in.	Tons per sq. in.
16	8·86	12·01
25	14·80	16·99
30	16·89	19·94
40	20·24	20·91
45	18·88	24·10
55	22·96	23·62
70	19·84	20·79

TABLE 10.

Compression Tests.

Sand-Castings.

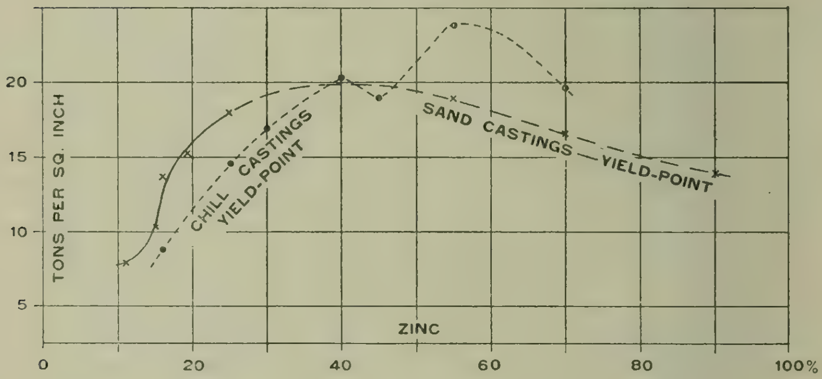
No. of Alloy.	Yield-Point.	Collapsing Stress.
	Tons per sq. in.	Tons per sq. in.
11	7·95	—
15	10·23	—
16	13·78	16·21
19	15·24	18·09
20	16·62	18·19
25	17·90	19·70
55	18·86	19·57
90	13·93	15·24

specimen, the beam dropping finally. Under this load most of the specimens bent into the shape of an open S, only a few specimens actually breaking—but when fracture did occur the specimens always broke into three pieces. The bending of the specimens was, of course, accompanied by a sliding of one of the steel plates into which they were screwed—these were merely laid against the jaws of the testing-machine and were held by friction alone.

The results of these tests are tabulated in Tables 9 and 10 (page 363) and are shown graphically in Fig. 16. These tests were carried out, in consequence of a suggestion made to the authors, at a late stage of the Research, so that material was not available from the entire series of alloys; tests were therefore made only on those which were available, since the preparation of a fresh series for this purpose did not appear to the authors to be justified by the importance of the results.

Fig. 16.

Compression Tests on Sand- and Chill-Castings.



The results themselves show that in general terms the compressive strength of these alloys is approximately proportional to their tensile strength, although the yield-points in compression are always decidedly lower than the ultimate stress in tension—the yield-points in tension being so indefinite it is not possible to make a satisfactory comparison with those values. In the sand-castings the yield-point in compression reaches a maximum value of 18·86 tons per square inch for alloy No. 55, but this is very closely approached by No. 25 with a yield-point of 17·90 tons per square inch. In the chill-castings, No. 55 again stands highest of the alloys tested in this way, with a yield-point in compression of nearly 23 tons per square inch, and this is more than 50 per cent. higher than the corresponding figure for No. 25. This comparison is brought out more clearly by Fig. 16, where it will be seen that the curve of yield-points for chill-castings lies decidedly below that for sand-castings up to a concentration of 40 per cent., and it is only in alloys Nos. 55 and 70 that the chill-casting shows any marked advantage over the sand-casting in this respect. In comparison with the results of tensile tests, in which the chill-castings are always superior to the sand, this result is somewhat surprising.

The Microstructure of the Sand-Cast and Chill-Cast Alloys.—In conjunction with the results of tests on sand- and chill-castings taken throughout the whole binary series of aluminium and zinc alloys, it is interesting to examine the microstructures corresponding to the range of alloys which have been tested. These microstructures are illustrated by the photomicrographs (Figs. 17 to 52, Plates 11–17, inclusive).

The structure shown in Fig. 17, Plate 11, representing the sand-casting of alloy No. 5 is practically identical with that of the "pure aluminium" used in the present Research; the traces of a eutectic seen in the interstices of the homogeneous crystals are not due to the presence of zinc, but to other impurities, probably iron, present in the aluminium. In the chill-casting of the same alloy, Fig. 18, this impurity is entirely masked by the "core" structure of the aluminium-zinc solid solution. These cores become increasingly marked in the chills of successive alloys with increasing zinc-content, as shown by Figs. 20, 22, 24, 26 and 28, Plates 11–12. In Fig. 22 (alloy No. 15) the dendritic character of the cores richest in aluminium is particularly well marked, and it is interesting to notice that the dendrites there shown exhibit branches crossing one another at right angles and at angles near 45°. In this respect these dendrites of the γ solid solution contrast markedly with the dendrites of the β body which are seen in Fig. 52, Plate 17, where the occurrence of 60° angles is typical. In the sand-castings, illustrated in Figs. 21, 23 and 25, Plates 11–12, the formation of cores is also evident, but as a result of the slower cooling which they have undergone these alloys show a larger scale of crystallization and the cores are much less sharply defined. It is important to remember, however, that all these alloys—certainly up to and including No. 30—can be rendered perfectly homogeneous by prolonged annealing, although rapid cooling through the critical temperature (256° C.) may also be necessary to ensure perfect homogeneity. These alloys must not therefore be regarded as duplex; their structure is exactly analogous to that of a cast α brass.

Figs. 27 and 28, Plate 12, represent the alloys of highest specific tenacity, but reference to the curves of tensile strength, Figs. 10 and 12 (pages 348 and 354), shows that there is no very marked discontinuity of physical properties. Accordingly, we find the alloys retaining a very similar type of microstructure up to and including No. 50, Figs. 29 to 38, Plates 13–14, except in so far as the proportions of the cores are affected by the increasing proportion of zinc which is present in the alloys. This results in the gradual diminution in the scale of the whole microstructure, in spite of the fact that the increasing fusibility of the alloys and the consequent somewhat lower rates of cooling tend in the opposite direction. In the chill-castings there is further a curious reversal in the manner of etching which occurs between alloys Nos. 25 and 30. In Fig. 28, Plate 12, alloy No. 26, the cores of the dendrites have etched dark while the peripheral portions appear light. In Fig. 20, Plate 11, this relationship is reversed. It is not easy to suggest a sound explanation for this phenomenon, but it may perhaps be regarded as indicating the point in the series of solid solution where, in spite of the far from complete equilibrium, the presence of the dissolved β body first makes itself apparent.

Reference to the equilibrium diagram of these alloys as given in Fig. 1 (page 338) shows that a dotted continuation of the eutectic line FP is carried up to a zinc-content of 50 per cent. It has already been pointed out that this line merely indicates the fact that the eutectic in question is formed as a meta-stable constituent in alloys cooled with moderate rapidity down to that composition. We must therefore expect to find traces of this eutectic in the alloys after No. 55. Also, in the alloys lying to the left of the point H in the equilibrium diagram, corresponding to alloy No. 40, we may also look for traces of the reaction which occurs along the line GH, namely, the formation of the β compound, and its resulting decomposition along the line IJKL. In the alloys Nos. 40, 45, and 50 these traces are too minute to be evident on the scale of magnification used in the present series of photomicrographs. In Fig. 39, Plate 14, however, representing the sand-casting of alloy No. 55, the signs of the decomposition-products of the β compound are to be seen in the shape of minutely-laminated regions lying near the peripheries of the dendritic cores. In the chill-casting, Fig. 40, the rate of cooling has evidently been sufficiently rapid to inhibit the formation of the compound in question entirely. It is this more or less complete inhibition of the formation of the compound by the more rapid cooling of the chill-castings, and its partial formation and subsequent decomposition in the sand-castings, which is the cause of the difference in shape between the curves of Figs. 10 and 12 (pages 348 and 354).

The formation of meta-stable eutectic is quite well marked in the sand-casting of alloy No. 60, Fig. 41, Plate 15, where white areas of eutectic are visible in the interstices of the cored crystals. In the next alloy this meta-stable eutectic can also be recognized, although in Fig. 44, Plate 15, which represents the structure of the chill of alloy No. 65, the magnification of 100 diameters is not sufficient to show the eutectic clearly. Fig. 44a, however, shows a portion of the same field, under a higher magnification (350 diameters), in which a well-marked six-rayed dendrite can be recognized, and there the dark-etched eutectic can be clearly seen. A very similar description applies to the next photographs which represent the sand- and chill-castings of alloys Nos. 70 and 75. Only when we come to alloy No. 80, Figs. 49 and 50, Plate 17, do we reach the region of stable eutectic, whose presence can be readily recognized in the microstructures of both sand- and chill-castings. Finally, in alloy No. 90, whose structure is illustrated by Figs. 51 and 52, we see an example of the group of alloys in which the β compound crystallizes direct from the fusion, and we find it accordingly in the shape of its characteristic six-rayed dendrites, embedded in the ground-mass of eutectic. In the microstructure of the sand-casting, Fig. 51, signs of the subsequent decomposition of this compound are to be found, although such signs, in the form of a finely-laminated duplex structure in the dark constituent, are more clearly seen in the photograph of the sand-casting of the previous alloy, No. 80, Fig. 50. The microstructures of alloy No. 90 are of special interest since they explain the extremely rapid rise of tensile strength which is brought about by the addition of a few per cent. of aluminium to pure zinc, which has a tensile strength of about 3 tons per square inch as compared with the alloy No. 90, containing 10 per cent. of aluminium and 90 per cent. of zinc (approximately), which has a tensile strength of 15·5 tons per square inch. This is, of course, essentially to be ascribed to the strength and hardness of the compound Al_2Zn_3 (β) which forms so large a proportion of the micro-constituents of the alloy No. 90.

(3) *Study of the Wrought Alloys.*—The mechanical treatment of the alloys was carried out by the courtesy of the British Aluminium Company at their Milton Works, under the direct personal supervision of the authors, who desire to express their appreciation of the manner in which the whole facilities of those works were placed at their disposal for the experiments in question. The first series of rolling experiments were carried out with the billets of the original series of alloys, namely, Nos. 5, 9, 13, 15, 17, 20, 26 and 30. Subsequently it was found that the quantity of rolled material available was not sufficient for all the tests desired and a second series of billets was prepared with the intention of producing as nearly as might be duplicates of certain members of the first series.

This intention was approximately realized, but since the duplication was not quite exact, these alloys of the second series have been separately numbered in the present Report; they constitute Nos. 11, 16, 19 and 25. At the same time rolling experiments were also made on a certain number of selected ternary alloys, some of which will be referred to in the Appendix (page 441).

The procedure of rolling followed with the first batch of billets was the same as that adopted in connection with the light alloys described in the Ninth Report, except that the finished material of smallest diameter obtained by hot-rolling was $\frac{7}{8}$-inch diameter in place of the $\frac{13}{16}$-inch previously employed. As far as possible the materials obtained were in the form of hot-rolled bars $1\frac{1}{4}$ inches in diameter, hot-rolled bars $\frac{7}{8}$-inch diameter, cold-drawn bars $\frac{13}{16}$-inch and bars cold-drawn with annealing, also $\frac{13}{16}$-inch diameter.

In the case of the second series of billets a somewhat different course was pursued. In some cases all that was desired was a further large supply of the material in the form of $\frac{7}{8}$-inch diameter hot-rolled bars; in other cases it was thought desirable to try the effect of carrying both the rolling and cold-drawing processes down to smaller diameters. Certain of the alloys were therefore rolled down hot to diameters of half an inch, and portions of the material thus obtained were then drawn down to wire in the manner usually employed for aluminium.

Behaviour of the Alloys on Rolling.—In considering the behaviour of these alloys during rolling and drawing, it must be borne in mind that they were treated by means of machines and processes which have been developed and are usually employed principally for the treatment of pure aluminium, and the circumstances under which the experiments were made do not allow of any material modification of these processes. Such factors as speed of rolling or drawing and rate of reduction at each pass were fixed by the plant available and no adaptation to the special character of the materials was possible. When it is remembered that the tensile strength and hardness of some of these alloys approximates more closely to that of mild steel than of aluminium, it will be evident that the results described in the present Report must be regarded as inconclusive from this point of view; if these alloys could be treated by other methods specially adapted to them it appears very probable that considerably better results could be obtained.

Alloys Nos. 5, 9, 13, 15, 17, 20, and 26 were all rolled after heating in a furnace at the temperature usually employed for pure aluminium, about 400° C. (752° F.). With the exception of alloy No. 26 all these billets rolled out exceedingly well, but No. 26 developed some cracks at the second pass in the first stage of the rolling. It is interesting to note in general that the tendency to crack is strongest in these alloys during the first few passes through the rolls; once this stage has been safely passed subsequent treatment down to $\frac{7}{8}$-inch diameter gave little or no trouble. This indicates either that the temperature of the surface of the billets is too high when first introduced into the rolls, or that the initial passes are too severe.

It had not been anticipated at the outset that even the 25 per cent. of zinc alloy could be rolled into bars, but when it had been found that this could be done fairly readily, an attempt was made to roll a 30 per cent. alloy, in order to ascertain at what composition the limit was to be found. One billet of alloy No. 30 was tried, and although this was rolled to $1\frac{1}{4}$-inch diameter, it was found to be full of cracks, so that further work with it was useless.

The second batch of alloys (Nos. 11, 16, 19 and 25) also behaved satisfactorily during rolling, both to $1\frac{1}{4}$-inch and to $\frac{7}{8}$-inch diameter. All these, with the exception of Nos. 17 and 25, were also rolled into $\frac{1}{2}$-inch bars and in this stage also behaved satisfactorily. Profiting by the experience gained with the first batch of alloys and guided also by the indications of forging tests to be described below, these later alloys were rolled at distinctly lower temperatures than those of the first batch. The temperatures in this case were measured by means of a thermo-couple placed on the billet. In order to secure that the temperature of the thermo-couple should be as nearly as possible identical with that of the billet, a small aluminium casting of a saddle form was heated with the billet. This served as a cover to the thermo-couple, which was thus protected from the influence of surface-cooling. The rolling temperatures adopted varied from 315° C. (599° F.) in the case of No. 11 to 364° C. (687° F.) for No. 19. With these lower temperatures the alloys were amply soft enough for rolling, and their behaviour was generally more satisfactory.

Behaviour on Cold-Drawing.—Portions of the material of each of these alloys, which had been cut off from the $1\frac{1}{4}$-inch bars, were used for drawing experiments, the object aimed at being to reduce them by steps of $\frac{1}{16}$-inch down to a diameter of $\frac{13}{16}$-inch. Nos. 5, 9, 13, and 15 all stood this treatment well except that No. 13 showed some surface spills. No. 17 broke hollow at the fifth draft, No. 20 was slightly spilly, while No. 26 broke at the second draft. Another set of pieces from the $1\frac{1}{4}$-inch bars were first cold-drawn in steps of $\frac{1}{16}$ of an inch down to a diameter of 1 inch; they were then annealed in the manner usual in the practice of aluminium, and were then further drawn down to $\frac{13}{16}$-inch diameter. All the alloys behaved well under this treatment except that No. 13 showed some surface spills. This surface spilling of No. 13 is probably attributable to a slight defect in the original billet rather than to any peculiarity of this alloy.

Behaviour of the Alloys on rolling into Sheets.—Two of the more promising members of the present series of alloys were also rolled into sheet form. For this purpose rolled slabs were cast in sand in the small foundry attached to the laboratory; these slabs measured $13\frac{1}{4}$ by $10\frac{1}{4}$ by $1\frac{1}{8}$ inches. They were treated at Milton in the same manner as is customary with aluminium slabs, being first heated to about 400° C. (752° F.), but before passing into the rolls they were cooled to a temperature just above 300° C. (572° F.). They were then broken down to a thickness of 0·13 inch, and then annealed at about 400° C. and after cooling were cold-rolled down to a thickness of 0·07 inch. Alloy No. 15 behaved satisfactorily under this treatment, but No. 20 exhibited a small amount of cracking at the edges of the sheet, a defect which may have arisen from roughness of the original casting.

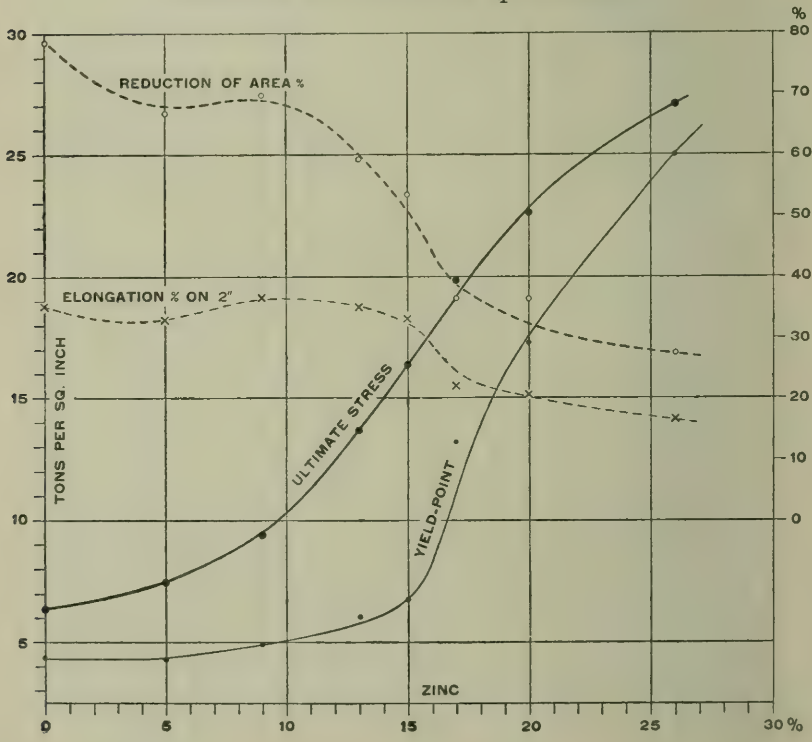
TABLE 11.

Tensile Tests on Hot-Rolled Bars $1\frac{1}{4}$-inch diameter.

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 in.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
5	4·3	7·48	0·57	33	66·8
9	4·9	9·41	0·50	36·5	69·8
13	6·1	13·67	0·45	35	59·2
15	6·8	16·38	0·42	33	53·4
17	13·2	19·85	0·66	22	36·3
20	17·3	22·64	0·76	20·5	36·3
26	25·0	27·09	0·92	16·5	27·5

Fig. 53.

Tensile Tests on Hot-Rolled Bars $1\frac{1}{4}$ inch diameter.



The material obtained by these various processes has been utilized for a large series of mechanical tests intended to demonstrate the properties and behaviour of these alloys under all the various conditions of engineering usage. These tests will now be described in detail.

(1) *Tensile Tests: Material Hot-Rolled to $1\frac{1}{4}$-inch diameter.*—The results of tensile tests on specimens of the standard shape cut from $1\frac{1}{4}$-inch bars are tabulated in Table 11 (page 372) and represented graphically in Fig. 53 (page 372). The results for ultimate stress given in the Table and plotted in the diagram are in every case the higher of at least two duplicate tests. These duplicates, however, exhibit very close agreement; the largest difference between any two is 0·88 of a ton, but in five cases the duplicates agree within 0·2 of a ton.

TABLE 12.

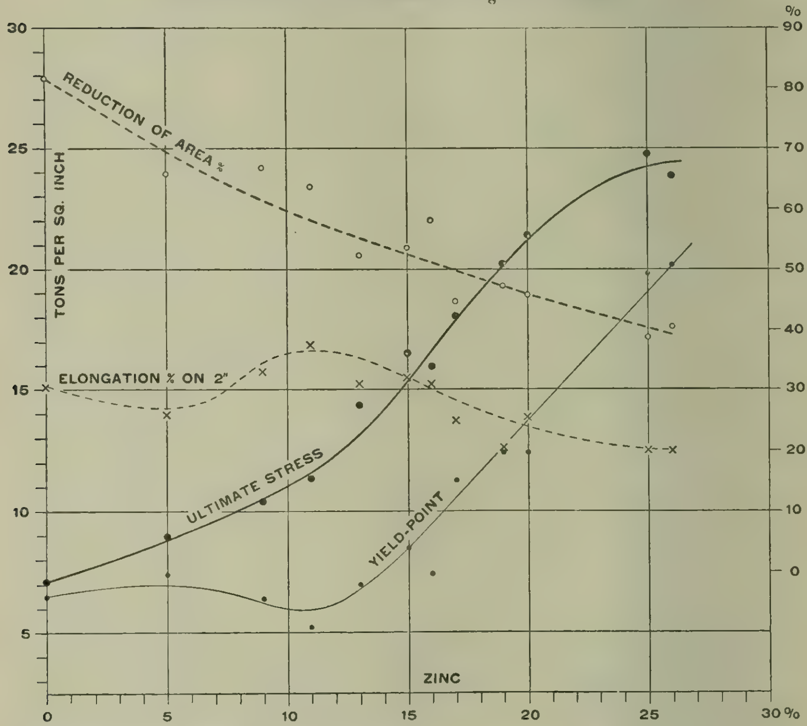
Tensile Tests on Hot-Rolled Bars $\frac{7}{8}$-inch diameter.

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 in.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
5	7·4	8·94	0·83	26	65·89
9	6·4	10·39	0·62	33	66·78
11	5·22	11·34	0·46	37·5	63·66
13	7·0	14·34	0·49	31	52·25
15	8·5	16·54	0·51	32	53·54
16	7·4	16·00	0·46	31	58·13
17	11·3	18·10	0·62	25	44·66
19	12·4	20·24	0·61	20·5	47·15
20	12·4	21·40	0·58	25·5	45·84
25	19·8	24·77	0·81	20	38·93
26	20·2	23·86	0·84	20	40·51

Figures for the yield-points as given in the Tables are in every case the mean of at least two duplicate tests, but in this case, in striking contrast with the tests of the cast alloys, duplicate observations of yield-points are in the closest agreement, particularly with the alloys richer in zinc, such as Nos. 15, 17, 20, and 26; in the three latter the maximum divergence in observations of the yield-stresses is 0·4 of a ton. This close agreement is due to the fact that in the rolled condition these alloys exhibit a well-defined yield-point accompanied by a sharp drop of the beam of the testing-machine similar to that found in the testing of mild steel. As regards elongation the duplicate observations are also in close agreement, the maximum variation being 2 per cent.

Fig. 54.

Tensile Tests on Hot-Rolled Bars $\frac{7}{8}$-inch diameter.



It will be seen that in this condition the alloy No. 26 attains a tensile strength of 27 tons per square inch with a yield-point of 25 tons per square inch and an elongation of 16·5 on 2 inches. Alloys Nos. 17 and 20 also give fairly high tensile strength combined with somewhat greater ductility. The curves of Fig. 53 (page 372) show the relation between zinc-content and mechanical properties as defined by these tensile tests on $1\frac{1}{4}$-inch bars. It will be seen that the ultimate stress for alloys containing from 10 per cent. zinc upwards is almost a linear function of zinc-content, the slight departure of this curve from the straight line being, however, accentuated in the curve of yield-points, and still more so in the curves of elongation and reduction of area.

The behaviour of these alloys when rolled down to a diameter of $\frac{7}{8}$ of an inch is shown in the data of Table 12 (page 373) and the curves of Fig. 54. In the Table the figures for ultimate stress are again the highest of at least two determinations. In one case only (No. 20) is the difference between the duplicate as much as 1·6 tons; for all the other alloys of this Table the agreement between duplicates is within 0·6 ton. The yield-points given are the means of at least two determinations; in these, however, rather wider variations between duplicates are found; for alloys Nos. 5 to 15 inclusive the duplicates agree within 0·2 ton, but in the case of No. 17 there is a divergence of slightly over 1 ton and in No. 20 this reaches a value of 4 tons. The yield-points are, however, quite well-defined even in these cases. As regards elongation and reduction of area this series of alloys gave remarkably uniform results, the maximum difference between duplicates being 1 per cent.

The general shape of the curves of Fig. 54, representing the results of tensile tests on the alloys in the form of hot-rolled material $\frac{7}{8}$-inch in diameter, is very similar to that of the curves of Fig. 53, which represent the tests of $1\frac{1}{4}$-inch bars; in the present series, however, a larger number of individual alloys were available for test so that a larger number of observed points could be inserted in the Figure. With one or two exceptions, all these points appear to lie on smooth curves; where an individual alloy has been found to give results which lie away from such curves the authors have felt justified in drawing the curve as still representing the majority of their results, leaving the reader to form his own opinion as to the extent to which these curves can be regarded as established by the evidence as indicated by the observed points. In some cases, such as Figs. 54 and 57, the curves appear to represent the facts with sufficient closeness; in other cases, where fewer observations are available, the curves must necessarily be regarded as quite tentative and rather as a means of connecting observations of the same kind than as expressions of any real continuous relationship between the quantities plotted.

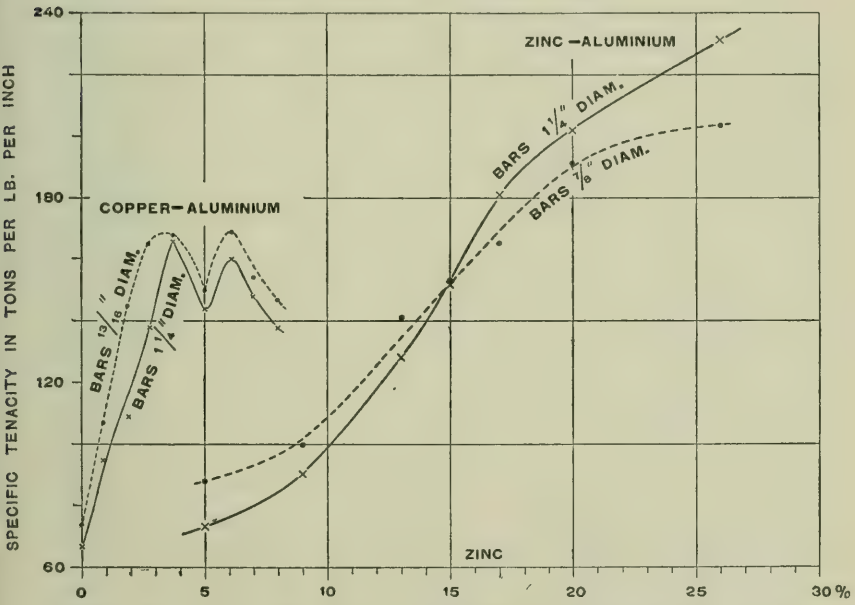
Reference to the Eighth and Ninth Reports of the Alloys Research Committee will at once show that, in the case of all the aluminium alloys there described, the tensile tests on hot-rolled material gave higher results the smaller the section of the bar tested, i.e. in those Reports the tensile tests on $\frac{13}{16}$-inch bars gave appreciably higher results than those on $1\frac{1}{4}$-inch bars. In the present series of alloys this is the case only for the first few members of the series, in which the zinc-content lies below 12 per cent.; as soon as an alloy with 15 per cent. of zinc is reached, it is found that the tests on $1\frac{1}{4}$-inch material are very slightly better than those on the $\frac{7}{8}$-inch bars, and the superiority of the thicker material asserts itself very markedly as the zinc-content increases, until, for alloy No. 26, the ultimate stress in the form of $1\frac{1}{4}$-inch bar is 27 tons per square inch as against an ultimate stress of only 23·86 tons per square inch for the $\frac{7}{8}$-inch bar.

The general result that the alloys containing more than 15 per cent. of zinc appear to deteriorate when a large amount of "work" is put on them is borne out by other tests on wrought material, and it is graphically illustrated in two further diagrams. In Fig. 58 (page 382) the results of tensile tests on these alloys in a variety of conditions are plotted together, so far as ultimate stresses are concerned, and it will be seen that several of the curves for wrought material cross near a zinc-content of 15 per cent. This diagram will, however, be referred to again in connection with the tensile tests on $\frac{1}{2}$-inch bars and on wire.

In Fig. 55 the specific tenacities of the alloys in the form of $1\frac{1}{4}$- and $\frac{7}{8}$-inch bars are plotted in the same manner as was done for the cast alloys in Fig. 15 (page 361), while the corresponding data are given in Table 8, columns 3 and 4. Since the specific gravities of the alloys do not differ materially when in the two conditions now under discussion, it follows that the specific tenacity curves will cross at or near 15 per cent. of zinc, in much the same manner as the curves of ultimate stress which are shown (with others) in Fig. 58 (page 382). The specific tenacity curves are, however, of interest from other points of view. Thus their constant upward trend shows that the effect of increasing the zinc-content up to 26 per cent. continually increases the specific tenacity, that is, the effect of zinc on the tensile strength is proportionately more rapid than its effect on the specific gravity of the alloys. These curves, and indeed all the curves based upon tensile strength determinations, suggest the desirability of pushing the zinc-content still higher than 25 per cent., but with an alloy containing 30 per cent. of zinc the authors found that the limit had been passed so far as the possibility of hot-rolling is concerned. By adopting special methods, and more particularly by exposing the billet to prolonged annealing before attempting to roll it, successful rolling

Fig. 55.

Specific Tenacities of Hot-Rolled Alloys.



of even the 30 per cent. alloy might be accomplished, but as will appear from the Appendix, superior results are obtained by the addition of small percentages of copper to alloys containing from 15 to 25 per cent. of zinc, so that efforts in the direction indicated have not been carried further by the authors.

From the point of view of practical use, however, it is interesting to notice that in the case of even the 1¼-inch bars the specific tenacity is only increased from 202 to 231 (or slightly more than 14 per cent.) by an increase in the zinc-content from 20 to 25 per cent. On the other hand, this increase in zinc-content is accompanied by a decrease in ductility of 4 per cent. from 20·5 to 16·5. On this ground it would seem that the 20 per cent. alloy is preferable to the 25 per cent. for all those purposes where ductility is of importance.

Before leaving the discussion of the tensile tests on the alloys in the form of rolled bars of 1¼-inch and ⅞-inch diameter, it is perhaps interesting to point out that, of *binary* aluminium alloys of comparatively low specific gravity, the 25 per cent. alloy in the form of 1¼-inch bar has the highest tensile strength yet recorded, so far as is known to the authors. As regards specific tenacity also, these alloys stand very high. For purposes of comparison, the specific tenacities of the light alloys of aluminium with copper have been inserted in the left-hand side of Fig. 55. It will be seen that these do not surpass 170 as compared with the value 231 attained by alloy No. 26 of the present series. Comparison with a mild steel having a tensile strength of 30 tons per square inch, coupled with a specific gravity of 7·85, shows that the steel has a specific tenacity of only 105·3, so that the best of the present alloys are equivalent in this respect to a steel of approximately the same specific gravity but having a tensile strength of over 60 tons per square inch, and this combined with reasonable ductility can only be obtained in specially treated alloy steels. The only material whose specific tenacity is superior to that of the present alloy No. 26 is the aluminium-copper-manganese-magnesium alloy known as Duralumin, whose tensile strength in the same form is slightly higher, while its specific gravity is also somewhat lower. On the other hand, this special alloy is a complex substance compared with the present simple binary alloy, and its special strength is only developed as the result of special thermal treatment, which is not necessary in the present case. Further, it is probable that the hardening action of magnesium which is found to occur with aluminium and many of its alloys may also occur with the aluminium-zinc alloys. If these are used as a basis, a ternary alloy with a small quantity of magnesium should produce far better results than any yet attained. The addition of copper in small quantities to these simple binary alloys has already been partially studied by the authors, and the results given in the Appendix dealing with these indicate that they are distinctly superior to the binaries, and even without the addition of magnesium approach very closely to the best results obtainable with "Duralumin."

Although in the previous Reports to the Alloys Research Committee no tests on material of smaller section than $\frac{13}{16}$-inch diameter have been included, the authors thought it desirable in the present research to carry the tests further in the direction of material whose section has been still more reduced both by hot-rolling and by drawing. The interest of these tests lies in the fact that light alloys are frequently employed in the form of thin wires, rods and drawn sections, and that figures of the tensile strength of industrial light alloys are frequently quoted in reference to such thin sections. It therefore became desirable to ascertain what improvement in the mechanical properties, if any, would be obtained by these further reductions in section. As it has already been pointed out that rolling these alloys down from $1\frac{1}{4}$-inch to $\frac{7}{8}$-inch diameter affected them adversely, improved properties will not be anticipated in the thinner rods and wires, but this result could not be foreseen by the authors at the time when the tests were planned and made.

Tensile Tests on Bars hot-rolled to $\frac{1}{2}$-inch diameter.—These were made on test-pieces turned up from the rolled rod, the dimensions of the test-pieces being those indicated in the drawing, Fig. 56 (page 380). The test-pieces were thus of the proportions of length to diameter recommended by the Engineering Standards Committee, but this necessitated the measurement of elongations on lengths of 1 inch only. A few preliminary tests made on the ½-inch bars as rolled, simply held in the grips of the testing-machine without any previous preparation, indicated that very slightly better results would be obtained in this way, that is, by testing the material without removal of the outside skin. There is, however, in the harder alloys at all events, a considerable tendency to break at the grips, and for comparison with the ⅞- and 1¼-inch material the use of turned specimens from which the outer skin has been removed is more suitable. The results of these tensile tests on the ½-inch bars are given in Table 13 and are represented graphically in

Fig. 56.—*Test-piece.*

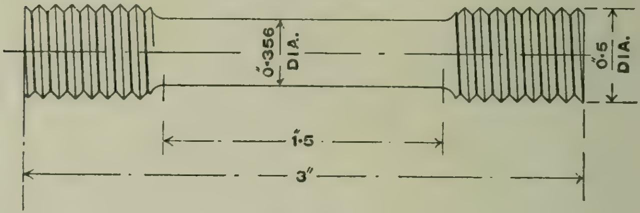


TABLE 13.

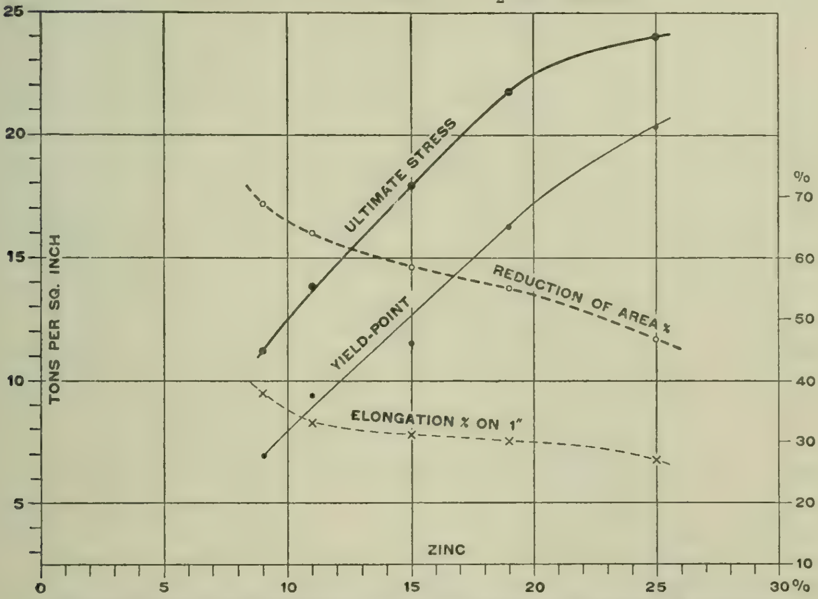
Tensile Tests on Hot-Rolled Bars ½-inch diameter.

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 1 inch.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
9	6·98	11·17	0·62	38	68·3
11	9·42	13·78	0·68	33	63·7
15	11·61	17·92	0·65	31	58·5
19	16·24	21·85	0·74	30	54·7
25	20·34	24·03	—	27	46·6

Fig. 57. A comparison of Table 13 with Tables 11 and 12 representing the tests on $\frac{7}{8}$- and $1\frac{1}{4}$-inch bars at once shows the effect of the further hot-rolling, and this comparison, so far as ultimate stresses are concerned, is still more clearly shown in Fig. 58 (page 382), where it is seen at once that alloys up to about 17 per cent. of zinc have been slightly improved in tensile strength both as compared with the $\frac{7}{8}$- and the $1\frac{1}{4}$-inch bars, but near a zinc-content of 20 per cent. the advantage of the additional "work" disappears entirely and for alloys still richer in zinc the additional "work" again proves a disadvantage. A comparison of the yield-points, which have not been plotted in Fig. 58, gives a somewhat similar result; the yield-stresses of the alloys of lower zinc-content are appreciably raised when the cross-section is reduced by rolling, but this relative rise of the yield-point ceases with the alloy No. 19.

Fig. 57.

Tensile Tests on Hot-Rolled Bars $\frac{1}{2}$-inch diameter.



The comparison which has just been made between the tensile properties of the alloys after hot-rolling to three different sizes suggests that perhaps the peculiarities which have been observed are not entirely due to the mere application of work in the hot state, but that the finishing temperatures and other conditions may have varied in such a way that the final states of the alloys in the three sizes may not be really strictly comparable. Some of them may have received more "cold work" and consequent hardening and stiffening. Now the effects of such "cold work" can be more or less completely removed by annealing the finished material, and consequently, if the effects described are due to such causes, we might expect the various kinds of material to become exactly alike after such annealing; if, on the other hand, the effect of work is of more deep-seated nature, then we should not anticipate that a short annealing—such as an exposure for one hour to a temperature of 400° C. (752° F.)—would entirely obliterate it. A series of

Fig. 58.
Effect of Work on the Alloys.

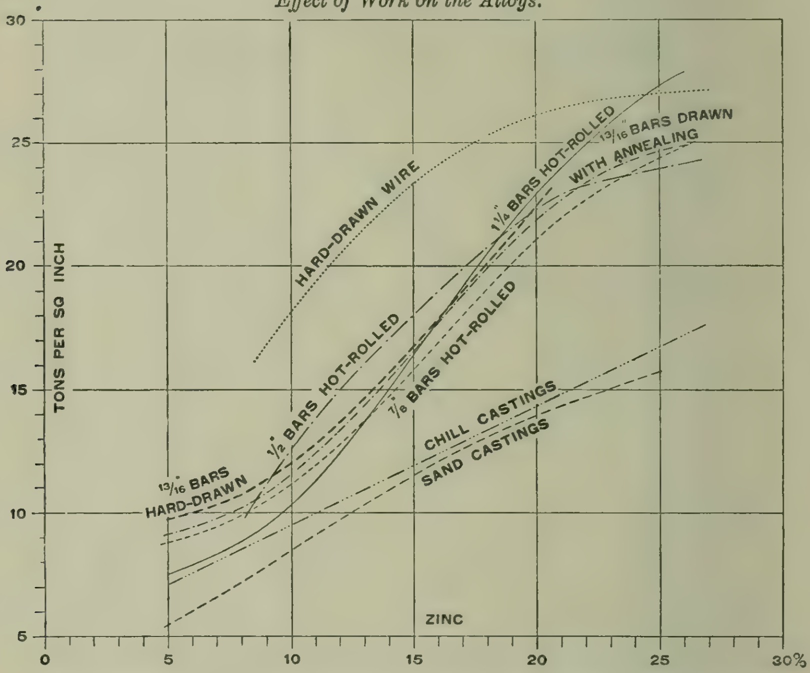


Fig. 59.

Tensile Tests on Hot-Rolled Bars $\frac{7}{8}$-inch diameter after Annealing at 400° C. (752° F.).

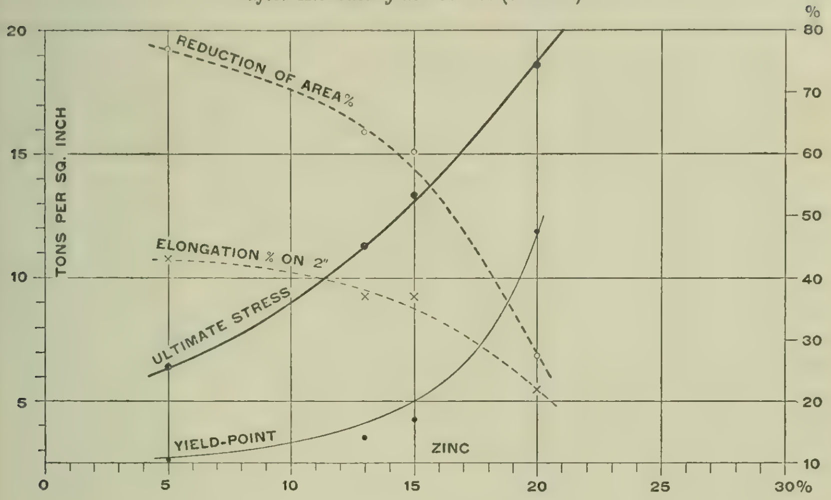


TABLE 14.

Tensile Tests on Hot-Rolled Bars $\frac{7}{8}$-inch diameter after Annealing at 400° *C.* (752° *F.*).

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
5	2·61	6·34	0·41	43	77
13	3·54	11·3	0·31	37	63·7
15	4·25	13·34	0·32	37	60·4
20	11·81	18·7	0·63	22	27·5

Fig. 60.

Tensile Tests on Hot-Rolled Bars ½-inch diameter after Annealing at 400° C. (752° F.).

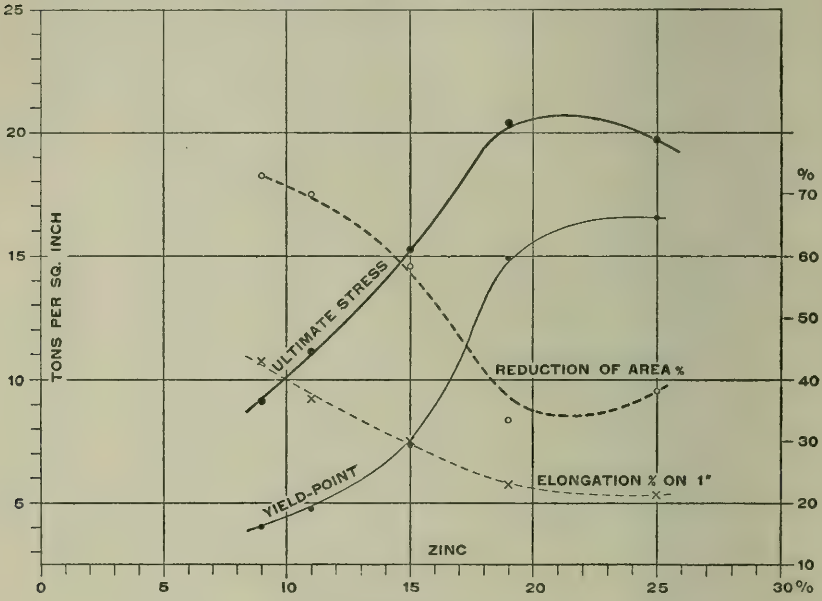


TABLE 15.

Tensile Tests on Hot-Rolled Bars ½-inch diameter after Annealing at 400° *C.* (752° *F.*).

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 1 inch.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
9	4·1	9·16	0·44	43	72·97
11	4·80	11·12	0·34	37	69·94
15	7·38	15·26	0·47	30	58·29
19	14·9	20·43	0·72	23	33·56
25	16·54	19·75	0·84	21·5	38·20

Fig. 61.

Tensile Tests on Cold-Drawn Bars $\frac{13}{16}$-inch diameter after Annealing at 400° C. (752° F.).

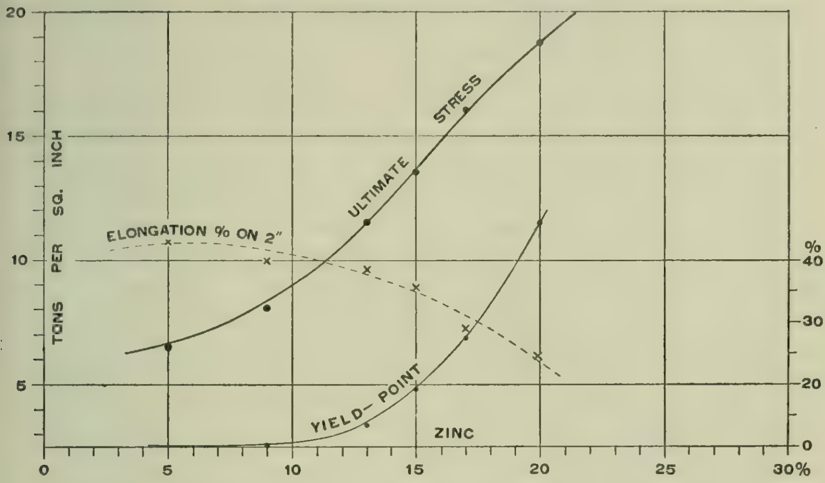


TABLE 16.

Tensile Tests on Cold-Drawn Bars $\frac{13}{16}$-inch diameter after Annealing at 400° *C.* (752° *F.*).

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
5	2·45	6·57	0·37	43	77·1
9	2·46	8·08	0·30	40	69·6
13	3·38	11·46	0·29	38·5	55·8
15	4·78	13·60	0·35	35·5	49·5
17	6·89	16·16	0·42	29	40·6
20	11·42	18·76	0·60	24·2	37·8

TABLE 17.

Comparison of Tests on Annealed Material.

No. of Alloy.	Size and Original Condition.	Yield-Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
5	Hot-rolled $\frac{1}{2}$-inch bar	3·10*	6·25*
	Hot-rolled $\frac{7}{8}$-inch bar	2·61	6·34
	Cold-drawn $\frac{13}{16}$-inch bar	2·45	6·57
13	Hot-rolled $\frac{1}{2}$-inch bar	3·80*	13·25*
	Hot-rolled $\frac{7}{8}$-inch bar	3·54	11·30
	Cold-drawn $\frac{13}{16}$-inch bar	3·38	11·46
	Cold-drawn wire	7·00*	15·00*
15	Hot-rolled $\frac{1}{2}$-inch bar	7·38	15·26
	Hot-rolled $\frac{7}{8}$-inch bar	4·25	13·34
	Cold-drawn $\frac{13}{16}$-inch bar	4·78	13·60
	Cold-drawn wire	9·25	18·20*
	Cold-rolled sheet 0·07 inch (long.)	7·38	14·83
20	Hot-rolled $\frac{1}{2}$-inch bar	14·90	20·43
	Hot rolled $\frac{7}{8}$-inch bar	11·81	16·70
	Cold-drawn $\frac{13}{16}$-inch bar	11·42	18·76
	Cold-drawn wire	13·80*	21·10*
	Cold-rolled sheet (long.)	11·87	18·28

* These figures are obtained by interpolation from the curves of Figs. 60 and 84 (pages 384 and 394); the actual tests of these bars and wires are given in Tables 15 and 20.

specimens were therefore annealed in this manner, the material chosen for this purpose being the bars which had been hot-rolled to $\frac{7}{8}$ and $\frac{1}{2}$ inch respectively, and bars which had been first hot-rolled to $1\frac{1}{4}$-inch diameter and then cold drawn, in the manner already described, to a diameter of $\frac{13}{16}$ inch. The results of tensile tests on these three classes of annealed specimens are tabulated in Tables 14, 15 and 16, and they are represented graphically in Figs. 59, 60 and 61. In Table 17 are tabulated the values of the yield and ultimate stresses as found for these three classes of annealed material and also for annealed wire and sheet. In this Table it should be mentioned that the values for the yield and ultimate stress have in some cases been inserted from the corresponding curves, since it happens that the tests on annealed samples were not made on exactly the same alloys in all cases. These difficulties have arisen from the comparatively limited amount of material available for the very extensive series of tests undertaken, but in the present case the great smoothness of the curves in question renders the interpolation perfectly sound. The general result of the comparison of ultimate stresses, which is borne out also by a comparison of the other data such as yield-stress and elongation, is to show that for alloys Nos. 13, 15 and 20 the application of work appears to have a beneficial effect which is not entirely removed by annealing. The two kinds of material which have been reduced to practically the same cross-section, namely, the $\frac{7}{8}$-inch hot-rolled and the $\frac{13}{16}$-inch cold-drawn bars, give practically identical results except for the alloy richest in zinc (No. 20), and there the alloy which has been reduced by cold work is slightly superior—the yield-stresses and elongations are, however, identical. The $\frac{1}{2}$-inch material, after annealing, is decidedly superior to both the others except for alloy No. 5, where it is practically identical, but in making this comparison the smaller size of the test-pieces employed with the $\frac{1}{2}$-inch material must be borne in mind.

Tensile tests have also been carried out on the material obtained by the processes of cold-drawing and of cold-drawing with annealing, as described above in the general account of the mechanical treatment of the alloys. The results of these tests are given in

Fig. 62.

Tensile Tests on Cold-Drawn Bars $\frac{13}{16}$-inch diameter.

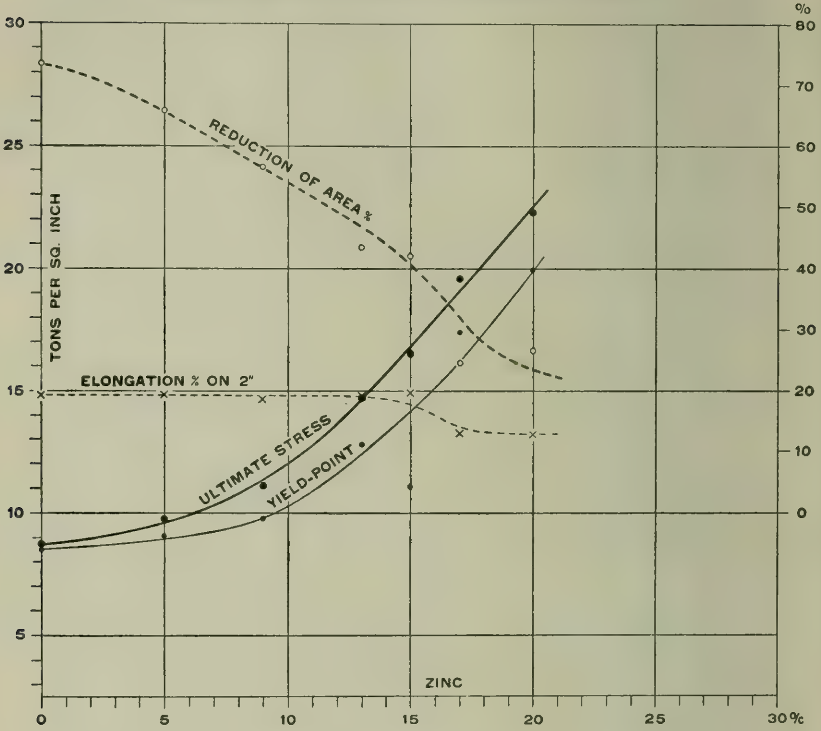


TABLE 18.

Tensile Tests on Cold-Drawn Bars $\frac{13}{16}$-inch diameter.

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 in.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
5	9·1	9·77	0·93	19·5	65·77
9	9·8	11·12	0·88	18·7	56·49
13	12·8	14·73	0·87	19·2	43·51
15	11·1	16·5	0·67	19·7	42·08
17	17·4	19·6	0·88	13	24·51
20	19·9	22·3	0·89	12·7	26·48
26	—	—	—	—	—

Fig. 63.

Tensile Tests on Bars Drawn with Annealing $\frac{13}{16}$-inch diameter.

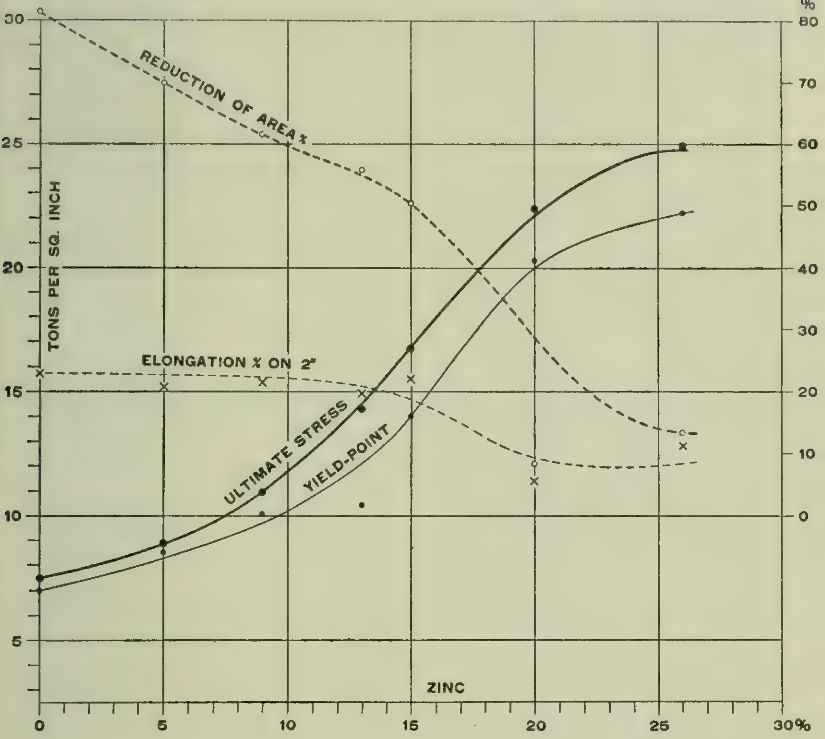


TABLE 19.

Tensile Tests on Bars Drawn with Annealing $\frac{13}{16}$-inch diameter.

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 in.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
5	8·5	8·88	0·96	20·7	69·94
9	10·1	10·92	0·92	21·5	61·66
13	10·4	14·3	0·73	19·7	55·72
15	14·0	16·75	0·84	22	50·21
20	20·3	22·36	0·91	5·5	8·33 cracked longitudinally
26	22·2	24·9	0·89	11·2	13·33

Tables 18 and 19 (pages 388–9), and they are graphically represented by Figs. 62 and 63. These results present some surprising features; perhaps the most remarkable is the fact that the ultimate stress of the cold-drawn bars is very little higher than that of the $1\frac{1}{4}$-inch hot-rolled bars from which they were drawn—in fact the alloys richer in zinc (above 15 per cent.) show a lower ultimate stress in the cold-drawn than in the hot-rolled state. Careful observation of these bars shows that this condition is not due to any hollow-drawing or other visible or microscopic fissures in the cold-drawn bars. That this inference is correct is further borne out by the fact that the elongations and reductions of area of the cold-drawn bars, although smaller than those of the hot-rolled, are still moderately large—far larger than could be obtained from even incipiently over-drawn material. The results obtained from bars drawn with annealing are similarly disappointing; the alloys lowest in zinc are slightly hardened as compared with the $1\frac{1}{4}$-inch hot-rolled material, but this effect ceases at 15 per cent. of zinc, and in the case of No. 26 the ultimate stress of the drawn is actually less than that of the hot-rolled bars. In this case, however, alloys Nos. 20 and 26 both show abnormally low extensions and reductions of area, so that a certain amount of incipient hollow-drawing is indicated, and this is further confirmed by the development of a longitudinal crack in the broken specimens of alloy No. 20. The net result of both these series of tests is to indicate that the higher alloys of the present series do not lend themselves to cold-drawing.

The comparative behaviour of the various forms of the same material, as brought out by the tensile tests which have just been described and discussed, is illustrated in an interesting manner by photomicrographs representing the structure of the material in these various forms. It will be seen that all the hot-rolled material consists of appreciably elongated crystals which indicate the fact that the working of the material has been continued down to a temperature below that at which rapid annealing occurs. These hot-rolled materials are accordingly to a considerable extent hardened by the work they have undergone, and it is therefore not surprising to find that the annealed specimens of the same material are distinctly softer.

Before describing the photomicrographs relating to these bars in detail, it should be remarked that in the majority of cases the polished specimens have been etched by caustic soda; this leaves the surface of the specimens covered with a dark deposit which, in the case of the rolled and drawn material, exhibits a banded appearance. In Fig. 66, Plate 18, this has been completely retained, while in Fig. 64 it has been partially removed. This deposit is of a carbonaceous nature, and it can be readily removed by immersing the specimen, after etching in caustic soda, in a weak solution of chromic acid. In this way the true structure of the material is revealed, and it is possible to obtain photographs of this structure showing the typical polyhedral crystals of a homogeneous material. The softness of the alloys, however, makes it difficult entirely to avoid minor scratches on the polished surfaces. All the alloys of the present series are strictly homogeneous, that is to say, there is no second constituent visible in any of them, except the aluminium-iron compound which is found in "pure" aluminium. The somewhat darker crystal boundaries visible on some of the photographs, such as Figs. 65, 76, 82, are entirely due to slightly deeper etching and not to the presence of another constituent in the boundaries.

Alloy No. 5 is represented by Figs. 64 and 65, Plate 18, in the form of $\frac{7}{8}$-inch hot-rolled bar, Fig. 64 representing the material as rolled and Fig. 65 after annealing for one hour at 400° C. (752° F.). It will be seen that in the annealed material the crystals have nearly if not quite completely resumed their normal equi-axial shape. Figs. 66 and 67 refer to alloy No. 13; in Fig. 66 the material is cold-drawn to $\frac{13}{16}$-inch diameter, while Fig. 67 gives the condition after annealing. Reference has already been made to the dark bands on Fig. 66, but beneath these can be seen the elongated crystals of the alloy. In Fig. 67 the crystals have entirely resumed their symmetrical shape, but the scale of the structure is comparatively very small. (The magnification throughout these photomicrographs relating to the wrought alloys is 100 diameters.) Figs. 68 to 74, Plates 18–19, inclusive, refer to alloy No. 15, and are representative of this material in the condition as hot-rolled to $1\frac{1}{4}$-inch diameter (Fig. 68), hot-rolled to $\frac{7}{8}$-inch (Fig. 69), the same after annealing (Fig. 70), $\frac{1}{2}$-inch hot-rolled bar (Fig. 71), the same after annealing (Fig. 72), and the $\frac{13}{16}$-inch cold-drawn bar (Fig. 73) and the same after annealing (Fig. 74). These photographs present a considerable range of structure varying from Figs. 71 and 73, where the crystals are considerably elongated, to Figs. 70 and 72, where the crystals are large and in the latter case symmetrical. A comparison of these photomicrographs with the corresponding figures from the tensile tests is instructive. It is found that the condition represented by Fig. 70 gives both the lowest yield-point and the lowest ultimate-stress, and in that condition the scale of the structure appears to be larger than in any other. On the other hand, among the annealed samples, Fig. 74 shows the smallest microstructure, and yet its tensile results are inferior to those of the material as represented by Fig. 72, whose crystals are distinctly larger. It follows, therefore, that crystal size, yield-point, and ultimate stress are not strictly proportional to one another. On the other hand, the high value for yield-stress and ultimate stress found in the $\frac{1}{2}$-inch rolled bar of this alloy is readily explained by Fig. 71, which shows a considerable amount of deformation and consequent hardening which the crystals have undergone in the material in that condition. In this respect Fig. 69, representing $\frac{7}{8}$-inch bars, is intermediate in character and the tensile results are similarly intermediate.

The next series of photographs, Figs. 75 to 80, Plates 19–20, inclusive, relate to alloy No. 19, the structure of the $\frac{7}{8}$-inch hot-rolled, $\frac{1}{2}$-inch hot-rolled and $\frac{13}{16}$-inch cold-drawn bars being shown both before and after annealing. A comparison of these figures with one another and with the results of tensile tests leads to a conclusion very similar to that stated for alloy No. 15. Comparison of Figs. 76, 79, and 80 again shows that the smallest structure in the annealed condition does not necessarily imply the highest tensile strength or yield-point. In the present case there is a very marked difference in the amount of deformation of the crystals between the

⅞-inch hot-rolled bar (Fig. 77), which shows considerable elongation, and the ½-inch hot-rolled bar (Fig. 75), which shows very little. On the other hand, the cold-drawn bar (Fig. 79) shows crystals elongated into fibres or rods, and these exhibit a cross-hatched structure which is frequently met with in copper alloys, particularly the α brasses when examined in similar circumstances. It has also been observed in the cold-drawn specimens of the alloys of the present series.

Figs. 81, 82, and 83, Plates 20–21, represent alloy No. 26 in the condition of 1¼-inch, ⅞-inch and ½-inch hot-rolled bars respectively. It will be seen that the amount of deformation of the crystals is very nearly the same in all three cases, although it is probably slightly more severe in Fig. 83 than in the others.

Tensile Tests on Cold-Drawn and Annealed Wires.—The authors wished to study the effect of wire-drawing, more particularly on the higher members of the present series of alloys. Those actually drawn and tested in the form of wire 0·1285 inch in diameter (No. 10 S.W.G.) were Nos. 9, 11, 19, 25 and 26. It had been the authors' intention to include No. 15, but through an error in marking the bars this alloy was omitted and No. 26 drawn in its place.

The results of tensile tests on these wires are given in Tables 20 and 21 (pages 394–5), representing the wires as drawn and after an hour's annealing at 400° C. (752° F.) respectively. These results are represented graphically in Figs. 84 and 85 (pages 394–5). It will be seen from these figures that the results for ultimate stress lie uniformly on a smooth curve, but those for yield-stress are somewhat erratically scattered. This is probably due to the fact that the total load at the yield-points is so small in these tests, while any slight want of straightness of the wire when put into the testing-machine may also affect the yield-point observations. These must therefore be regarded as approximate values only.

In the hard-drawn state it will be seen that the wires of all the alloys except Nos. 25 and 26 show a considerable increase of tensile strength as compared with the rolled bars or other forms of

Fig. 84.

Tensile Tests on Hard-Drawn Wire 0·1285-*inch diameter.*

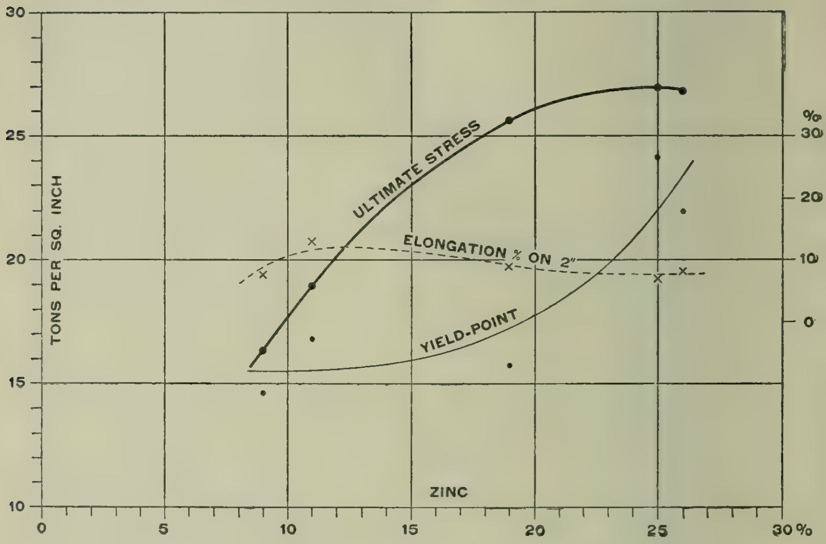


TABLE 20.

Tensile Tests on Hard-Drawn Wire 0·1285-*inch diameter.*

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	Tons per sq. in.	Tons per sq. in.	Per cent.
9	14·66	16·31	7·5
11	16·80	18·92	13
19	15·75	25·66	9
25	24·17	26·94	7
26	22·01	26·80	8·25

Fig. 85.

Tensile Tests on Wire 0·1285-*inch diam. after annealing at* 400° C. (752° F.).

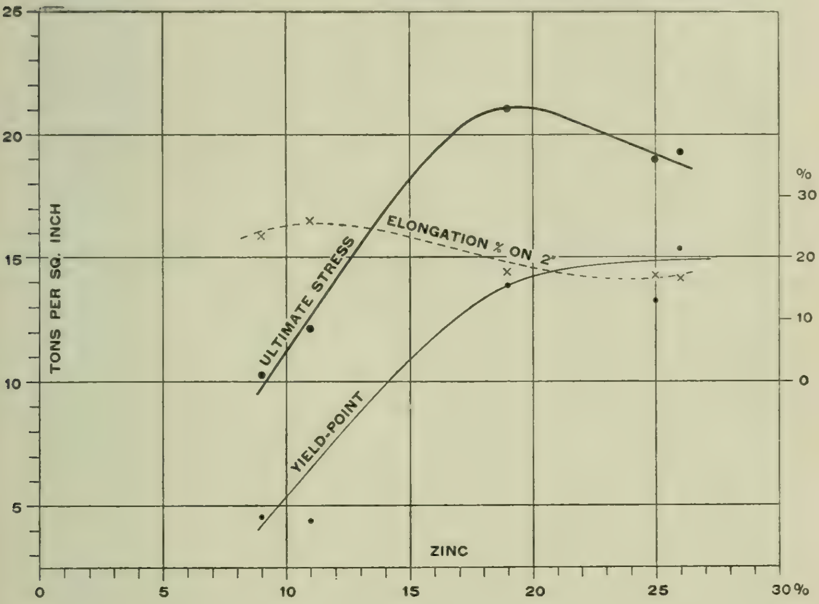


TABLE 21.

Tensile Tests on Wire 0·1285-*inch diameter after Annealing at* 400° *C.* (752° *F.*).

No. of Alloy.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	Tons per sq. in.	Tons per sq. in.	Per cent.
9	4·57	10·25	23·5
11	4·36	12·14	26
19	13·84	21·10	17·7
25	13·26	18·97	17
26	15·33	19·27	16·5

the same material. This is well shown in the diagram of Fig. 58 (page 382), which illustrates the effect of "work" on these alloys. The curve of ultimate stress for the hard-drawn wires lies considerably above those representing the tests on other forms of the same materials. This is well marked until a concentration of about 20 per cent. of zinc is reached, but then the curve representing the wires rapidly becomes much flatter and actually crosses the curve representing the $1\frac{1}{4}$-inch hot-rolled bars at a concentration just below 25 per cent. We thus arrive at the very remarkable result that no amount of further work, whether applied to the metal when hot or cold, increases the tensile strength of the 25 per cent. alloy beyond that which is attained in the form of the $1\frac{1}{4}$-inch hot-rolled bar, the only marked effect of cold work being to bring about some reduction in the ductility of the alloy.

The results obtained with the annealed wire, as shown in Fig. 85, are chiefly remarkable for the fact that they exhibit a well-marked maximum at a concentration near 20 per cent. of zinc. Near this concentration the tensile strength reaches a value of 21·1 tons per square inch together with an elongation of over 17 per cent. on two inches. A reference to Table 17 (page 386), where the results of all forms of annealed material are grouped together for comparison, shows that this value is the highest tensile strength attained by annealed material in the present series of binary alloys.

Tests on the Alloys in the form of Sheets.—For the purpose of ascertaining the behaviour of the harder alloys of the present series when rolled into sheets, alloys Nos. 15 and 20 were treated in this way, in the manner already described. From these sheets a series of test-pieces were cut in the same manner as that described in connection with the light alloys of aluminium and copper in the Eighth Report to the Alloys Research Committee, both longitudinal and transverse strips being cut in quadruplicate, two of each being tested in the condition of the sheet as rolled (i.e. cold rolled), while the two others were annealed before testing. Two thicknesses of sheet were available, namely, 0·13 inch (No. 9 gauge) and 0·07 inch (No. 15 gauge). The results of the tensile tests made on these

TABLE 22.

Tensile Tests on Sheet of 0·13-*inch thickness.*

No. of Alloy.	Yield-Point.		Ultimate Stress. Tons per sq. in.		Elongation on 2 inches. Per cent.	
	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.
15	12·05	13·17	15·58	17·98	5	12·75
20	8·88	11·85	12·41	22·08	0	0·5

TABLE 23.

Tensile Tests on Sheet 0·13-*inch thick after Annealing at* 400° *C.* (752° *F.*).

No. of Alloy.	Yield-Point. Tons per sq. in.		Ultimate Stress. Tons per sq. in.		Elongation on 2 inches. Per cent.	
	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.
15	4·26	3·01	13·23	14·14	10	33·25
20	13·32	15·27	14·90	20·44	15·5	18·5

TABLE 24.

Tensile Tests on Sheet of 0·07*-inch thickness.*

No. of Alloy.	Yield-Point.		Ultimate Stress. Tons per sq. in.		Elongation on 2 inches. Per cent.	
	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.
15	14·21	14·38	21·01	21·76	6·5	1·5
20	2·93	12·76	23·60	22·69	1·5	0·5

TABLE 25.

Tensile Tests on Sheet 0·07*-inch thick after Annealing at* 400° *C.* (752° *F.*).

No. of Alloy.	Yield-Point. Tons per sq. in.		Ultimate Stress. Tons per sq. in.		Elongation on 2 inches. Per cent.	
	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.
15	6·78	7·38	14·41	14·83	15	24·75
20	11·87	4·74	17·25	19·28	6·25	10·5

sheets in the condition as rolled are given in Tables 22 and 24 (pages 397–8), while those dealing with the tests after annealing are given in Tables 23 and 25. These results are most directly comparable with those obtained on bars drawn with annealing, since the process results in a partial hardening which is not, however, usually so complete as the hardening produced by wire-drawing. In the case of alloy No. 15, as rolled to a thickness of 0·13 inch, we find that the ultimate stress—taking the mean of the longitudinal and transverse results, which in this case lie very close together—is almost exactly the same as that of the bar drawn with annealing (*see* Table 19, page 389). The yield-point is, however, distinctly lower in the sheet (12·6 as compared with 14·0 tons per square inch). The ductility as measured by the elongation is also decidedly lower, the longitudinal elongation, although much better than that given by the transverse test, being only little more than half that found in the bars drawn with annealing, while even the hard-drawn bars give an elongation 50 per cent. greater than the longitudinal test from the sheet.

In the form of the thinner sheet (0·07 inch thick) we find that the yield-point and the ultimate stress have both been considerably raised, while there is little or no difference between longitudinal and transverse test-pieces in this respect. The ultimate stress in this condition is, however, considerably higher than that obtained from this alloy in any other form except that of hard-drawn wire (*see* Table 20, page 394). The elongation has, however, been almost completely abolished by the reduction of thickness, but it is curious to note that the transverse test-piece shows a small amount of extension (6·5 per cent.), while that of the longitudinal test has fallen to 1 per cent.

In the annealed condition (*see* Tables 23 and 25) these tests on sheet material are approximately comparable with those on wire after annealing (*see* Table 21, page 395). Thus we have alloy No. 20, in the form of sheet 0·13 inch thick, giving an ultimate stress of 20·4 tons per square inch with an elongation of 18·5 per cent. in a longitudinal specimen. Somewhat curiously, the transverse strength is still much lower, even in the annealed state, than the longitudinal. This observation again shows that the effect of severe cold work is not entirely obliterated by annealing. Somewhat in contrast with this conclusion, however, is the fact that the thinner sheet (0·07 inch) shows, in the annealed condition, a decidedly lower tensile strength than the same alloy (No. 29) in the thicker annealed sheet, so far as longitudinal specimens are concerned, while for transverse specimens the reverse is the case. Reference to Table 17 (page 386) shows the position of the annealed sheet in comparison with the annealed alloys in other forms, and although in both Nos. 15 and 25 the annealed sheet stands somewhat lower than the annealed wire, it is in both cases superior to the annealed $\frac{7}{8}$-inch bars. The authors attach particular importance to this comparison of the properties of the annealed material, since there are several important reasons why the use of hard-drawn or cold-rolled material is to be deprecated. Also, since the further study of the mechanical properties of these alloys has been conducted principally on material derived from the $\frac{7}{8}$-inch hot-rolled bars, the comparability of the sheet with such bars is of some interest.

Summary of Tensile Tests.—In order to facilitate reference and to enable the reader to verify for himself the various comparisons quoted in the several sections of this Report dealing with tensile tests, the results of all the tensile tests which have been described above have been tabulated for each of the alloys studied. These tabulations are given in Tables 26–35 (pages 401–7). A glance down the results columns of these Tables at once indicates the effect of the various forms of mechanical and thermal treatment upon that particular alloy. So far as the effect of "work" on ultimate stress is concerned, these Tables are represented graphically by Fig. 58 (page 382), to which reference has already been repeatedly made.

Further Study of the Alloys.—The authors had originally intended to carry out the further study of the alloys, and more particularly the dynamic tests, only on two or three selected alloys out of the series, but the results of tensile tests on the alloys in the wrought condition had proved so interesting and promising that they found

(*Continued on page* 407.)

TABLE 26.

Alloy No. 5.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	2·72	5·21	16	—
Chill-casting . . .	2·85	6·60	29	—
1¼-inch rolled bars . .	4·30	7·48	33	66·8
⅞-inch rolled bars . .	7·4	8·94	26	65·9
⅞-inch rolled bars annealed at 400° C. (752° F.) .	2·61	6·34	43	77·0
13/16-inch cold-drawn bars .	9·1	9·77	19·5	65·8
13/16-inch cold-drawn bars annealed at 400° C. .	2·45	6·57	43	77
13/16-inch bars drawn with annealing . . .	8·5	8·88	21	69·9

TABLE 27.

Alloy No. 9.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	5·03	8·52	9	—
Chill-casting . . .	3·86	7·79	11	—
1¼-inch rolled bars . .	4·7	9·41	36·5	69·8
⅞-inch rolled bars . .	6·4	10·39	33	66·8
½-inch rolled bars . .	6·98	11·17	38*	68·3
½-inch rolled bars annealed at 400° C. . . .	4·1	9·16	43*	73·0
13/16-inch cold-drawn bars .	9·8	11·12	19	56·5
13/16-inch cold-drawn bars annealed at 400° C. .	2·46	8·08	40	69·6
13/16-inch bars drawn with annealing . . .	10·1	10·92	21·5	61·7
Wire 0·1285-inch diameter	14·66	16·31	8	—
Wire 0·1285-inch diameter annealed at 400° C. .	4·57	10·25	23·5	—

* On 1 inch.

TABLE 28.

Alloy No. 11.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	6·4	9·41	8	—
Chill-casting . . .	4·9	10·24	16	—
7/8-inch rolled bar . .	5·20	11·34	38	63·7
1/2-inch rolled bar . .	9·42	13·78	33*	63·7
1/2-inch rolled bar annealed at 400° C. . . .	4·80	11·12	37*	69·9
Wire 0·1285-inch diameter	16·80	18·92	13	—
Wire 0·1285-inch diameter annealed at 400° C. .	4·36	12·14	26	—

TABLE 29.

Alloy No. 13.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	8·46	10·55	4	—
Sand-casting annealed at 400° C.	4·27	8·15	9	—
Chill-casting . . .	4·9	10·71	10·5	—
Chill-casting annealed at 400° C.	4·64	10·51	7·5	—
1 1/4-inch rolled bars . .	6·1	13·67	35	59·2
7/8-inch rolled bar . .	7·0	14·34	31	52·3
7/8-inch rolled bar annealed at 400° C. . . .	3·54	11·30	37	63·7
13/16-inch cold-drawn bars .	12·80	14·73	19·5	43·5
13/16-inch cold-drawn bars annealed at 400° C. .	3·38	11·46	38·5	55·8
13/16-inch bar drawn with annealing . . .	10·40	14·30	19·5	55·7

* On 1 inch.

TABLE 30.

Alloy No. 15.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	9·55	11·14	2	—
Sand-casting annealed at 400° C.	5·87	10·0	3·5	—
Chill-casting . . .	5·8	11·70	8·5	—
Chill-casting annealed at 400° C.	4·56	10·90	10	—
1¼-inch rolled bar . .	6·80	16·38	33	53·4
⅞-inch rolled bar . .	8·50	16·54	32	53·5
⅞-inch rolled bar annealed at 400° C. . . .	4·25	13·34	37	60·4
½-inch rolled bar . . .	11·61	17·92	31*	58·5
½-inch rolled bar annealed at 400° C. . . .	7·38	15·26	30*	58·3
$\frac{13}{16}$-inch cold-drawn bar .	11·1	16·50	20	42·1
$\frac{13}{16}$-inch cold-drawn bar annealed at 400° C. . .	4·78	13·60	36	49·5
$\frac{13}{16}$-inch bar drawn with annealing	14·00	16·75	22	50·2
Wire 0·1285-inch diameter annealed at 400° C. . .	15·33	19·27	16·5	—
Sheet 0·07-inch thick, transverse . . .	14·21	21·01	6·5	—
Sheet 0·07-inch thick, transverse, annealed at 400° C.	6·78	14·41	15	—
Sheet 0·07-inch thick, longitudinal	14·38	21·76	1·5	—
Sheet 0·07-inch thick, longitudinal, annealed at 400° C.	7·38	14·83	24·75	—
Sheet 0·13-inch thick, transverse	12·05	15·58	5	—
Sheet 0·13-inch thick, transverse, annealed at 400° C.	4·26	13·23	10	—
Sheet 0·13-inch thick, longitudinal	13·17	17·98	12·8	—
Sheet 0·13-inch thick, longitudinal, annealed at 400° C.	3·01	14·14	33·3	—

* On 1 inch.

TABLE 31.

Alloy No. 16.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	11·00	12·71	3·5	—
Chill-casting . . .	6·69	11·36	6·5	—
⅞-inch rolled bar . .	7·4	16·0	31	58·1

TABLE 32.

Alloy No. 17.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	10·23	12·13	1·0	—
Chill-casting . . .	5·8	13·60	5·2	—
1¼-inch rolled bar . .	13·20	19·85	22	36·3
⅞-inch rolled bar . .	11·30	18·10	25	44·7
13/16-inch cold-drawn bar .	17·40	19·60	13	24·5

TABLE 33.

Alloy No. 19.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	12·34	13·25	2·5	—
Chill-casting . . .	8·8	13·70	7	—
⅞-inch rolled bar . .	12·40	20·24	20·5	47·20
½-inch rolled bar . .	16·24	21·85	30*	54·7
½-inch rolled bar annealed at 400° C. . . .	14·90	20·43	23*	33·60
Wire 0·264-inch diameter .	21·43	23·54	19	—
Wire 0·264-inch diameter annealed at 400° C. .	15·73	20·67	20	—
Wire 0·1285-inch diameter	15·75	25·66	9	—
Wire 0·1285-inch diameter annealed at 400° C. .	13·84	21·10	18	—

* On 1 inch.

TABLE 34.

Alloy No. 20.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting	10·04	13·07	1	—
Sand-casting annealed at 400° C.	10·55	13·27	2	—
Chill-casting	7·84	13·82	4	—
Chill-casting annealed at 400° C.	7·56	12·95	2	—
$1\frac{1}{4}$-inch rolled bar	17·3	22·64	20·5	36·3
$\frac{7}{8}$-inch rolled bar	12·41	21·40	25·5	45·8
$\frac{7}{8}$-inch rolled bar annealed at 400° C.	11·81	18·7	22	27·5
$\frac{13}{16}$-inch cold-drawn bar	19·9	22·30	13	26·5
$\frac{13}{16}$-inch cold-drawn bar annealed at 400° C.	11·42	18·76	24·3	37·8
$\frac{13}{16}$-inch bar drawn with annealing	20·3	22·36	5·5	8·30
Sheet 0·07-inch thick, transverse	2·93	23·60	1·5	—
Sheet 0·07-inch thick, longitudinal	12·76	22·69	0·5	—
Sheet 0·07-inch thick, transverse, annealed at 400° C.	11·87	17·25	6	—
Sheet 0·07-inch thick, longitudinal, annealed at 400° C.	4·75	19·28	11	—
Sheet 0·13-inch thick, transverse	12·08	12·41	—	—
Sheet 0·13-inch thick, longitudinal	11·85	22·08	—	—
Sheet 0·13-inch thick, transverse, annealed at 400° C.	13·32	14·90	15·5	—
Sheet 0·13-inch thick, longitudinal, annealed at 400° C.	15·27	20·44	18·5	—

TABLE 35.

Alloy No. 26.

Condition.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Sand-casting . . .	11·22	17·33	2·5	—
Chill-casting . . .	10·6	17·72	4	—
1¼-inch rolled bar . .	25	27·09	16·5	27·5
⅞-inch rolled bar . .	20·2	23·86	20·5	40·5
13/16-inch bar drawn with annealing . . .	22·3	24·9	11·5	13·30

it desirable as far as possible to extend the complete study of the material over the whole range of alloys available in the wrought condition. This decision was further supported by the fact that, while in present practice alloys of comparatively low zinc-content (10 per cent. or less) are principally employed, the results of the present series of tests clearly indicate the superiority of alloys containing from 15 to 25 per cent. of zinc. Both groups of alloys thus appeared worthy of closer study.

The further tests actually undertaken are as follows:—

(1) Tensile tests at high temperatures.

(2) Determination of the elastic properties of the alloys, both hot-rolled and cold-drawn.

(3) Tensile tests on 8-inch specimens, with autographic stress-strain diagram.

(4) Torsion tests.

(5) Determination of hardness (Brinell and Scleroscope).

(6) Compression tests.

(7) Dynamic tests:—

(*a*) Carried out in the Engineering Department of the National Physical Laboratory:—

Alternating-stress tests and determination of safe ranges of stress.
Repeated-bending impact tests.
Single-blow impact test on the Izod machine.

(b) Carried out by Professor J. O. Arnold at Sheffield University:—
Repeated-bending tests.

(8) Corrosion tests.

Tensile Tests at High Temperatures.—The apparatus used and the mode of carrying out the tests were the same as those described in the Ninth Report to the Alloys Research Committee, except that the range of temperature employed in the present series was lower, while an accurate potentiometer was employed for measuring the temperatures in place of the portable galvanometer used in the previous series. Tests were made on alloys Nos. 9, 11, 13, 15, 17, 19, 20, 25 and 26. With the exception of Nos. 20 and 26, the tests were not carried beyond 200° C., at which temperature it was found that all the alloys had become excessively weak; the two alloys named, however, were carried to 600° and 400° C. (1,112° and

TABLE 36.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
9	50	122	5·07	8·38	33·75
	75	167	5·11	7·43	34·75
	100	212	4·49	6·67	39·75
	150	302	5·43	6·34	42
	200	392	3·94	4·44	62

TABLE 37.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
11	50	122	5·09	10·08	33·5
	75	167	4·67	8·41	36
	100	212	4·70	7·36	36·75
	150	302	4·31	5·74	44
	200	392	3·66	4·01	60

TABLE 38.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
13	50	122	8·19	12·72	30
	75	167	7·75	10·71	29
	100	212	6·77	9·21	33
	150	302	6·09	7·15	34
	200	392	4·96	5·31	48

752° F.) respectively, in the hope of detecting by this method the temperature at which the alloys become fragile and brittle. It was hoped in this way to determine the highest temperature at which the hot-rolling operation could be carried out successfully.

(*Continued on page* 414.)

TABLE 39.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
15	50	122	7·48	14·02	30
	75	167	6·18	11·60	34
	100	212	5·9	9·33	35
	150	302	5·28	7·01	34
	200	392	4·49	5·28	43·5

TABLE 40.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
17	50	122	11·8	16·90	27
	100	212	7·79	8·70	28
	160	320	5·23	5·23	38

TABLE 41.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature. °C.	Temperature. °F.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
			Tons per sq. in.	Tons per sq. in.	Per cent.
19	50	122	12·32	18·37	26·5
	75	167	9·80	15·75	27·5
	100	212	11·61	14·7	26
	150	302	10·39	12·24	25·5
	200	392	5·55	6·85	33

TABLE 42.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature. °C.	Temperature. °F.	Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
			Tons per sq. in.	Tons per sq. in.	Per cent.
20	100	212	11·4	14·02	18
	250	482	5·19	5·19	28·5
	300	572	3·74	3·74	28
	400	752	0·94	0·94	92
	500	932	0·39	0·39	92·5
	595	1104	0·35	0·35	130

TABLE 43.

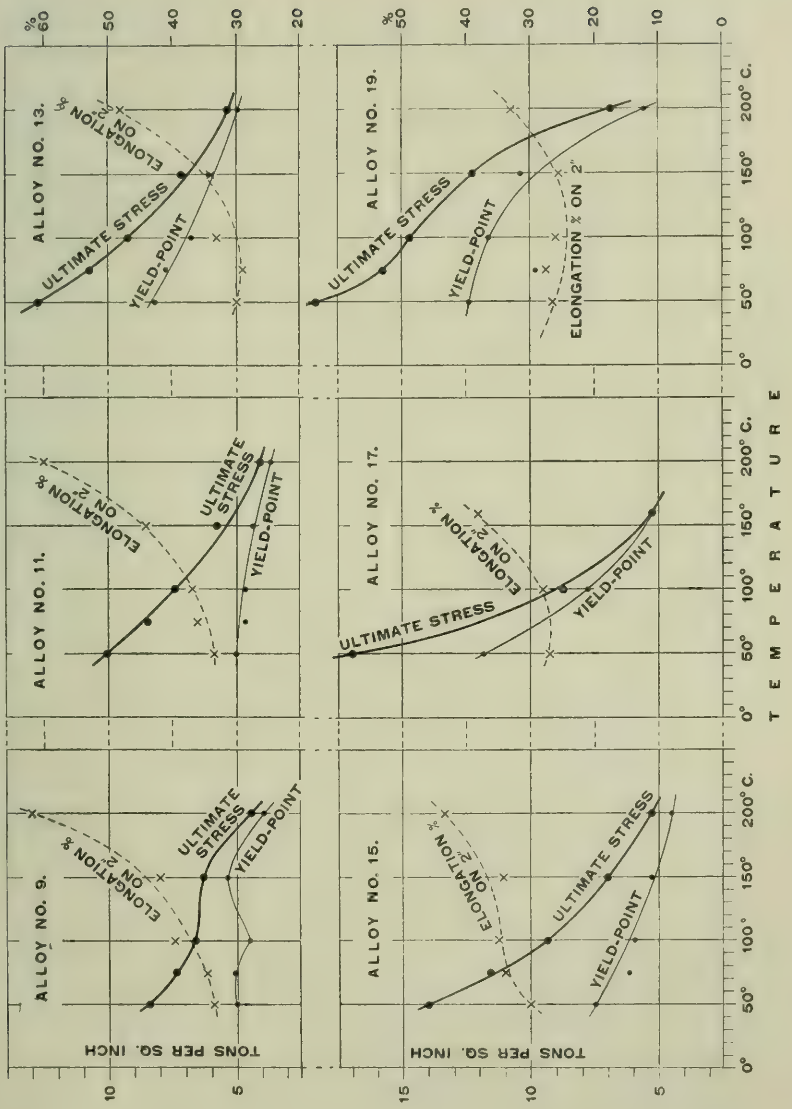
Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
25	50	122	17·88	22·68	21
	75	167	15·35	20·40	21·25
	100	212	14·82	18·29	21·25
	150	302	13·48	15·75	19
	200	392	9·74	10·94	18

TABLE 44.

Tensile Tests at High Temperatures.

No. of Alloy.	Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
	°C.	°F.			
			Tons per sq. in.	Tons per sq. in.	Per cent.
26	150	302	13·13	17·64	15·5
	200	392	10·57	10·57	11·5
	250	482	6·75	6·75	21·5
	300	572	4·08	4·08	28·5
	400	752	1·34	1·34	48

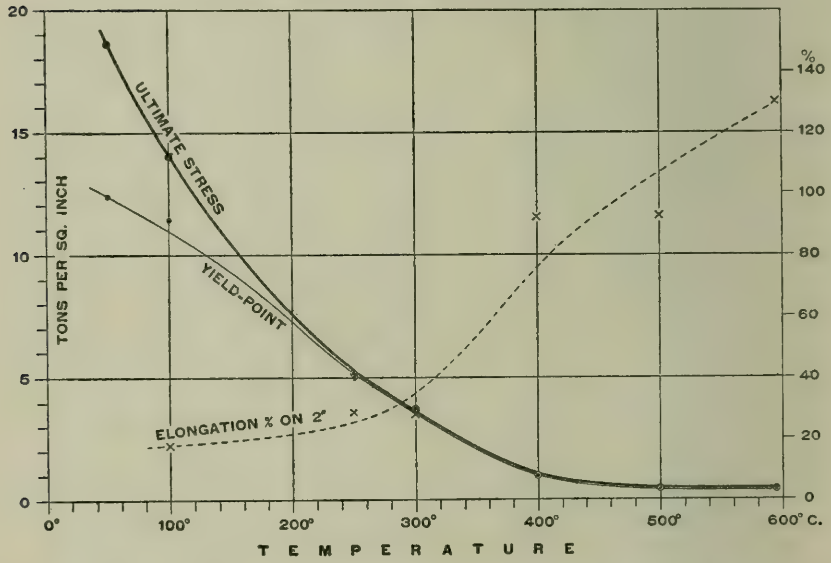


Figs. 86 to 91.—*Tensile Tests at High Temperatures.*

The results of the tensile tests at high temperatures are given in Tables 36 to 44 inclusive, while they are shown graphically by the diagrams of Figs. 86 to 94 (pages 413–5) inclusive. Each of these Tables and figures refers to a single alloy. In every case there is a rapid fall in the ultimate stress and yield-point with rising temperature; even the effect of 50° C. is quite marked in this respect, while at 100° C. there is a very decided loss of tensile strength. The rate of loss is, however, different in different alloys.

Fig. 92.

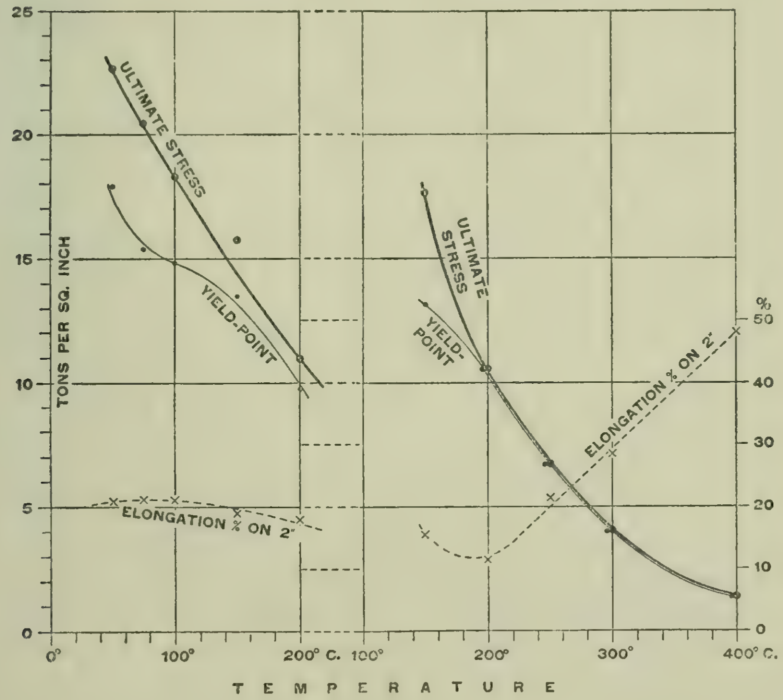
High Temperature Tensile Tests on Alloy No. 20.



Thus at 100° C. alloys Nos. 9, 11, and 13 have lost about 36 per cent. of their ultimate stress at the ordinary temperature; this figure rises to 44 per cent. for No. 15 and is as high as 52 per cent. for No. 17, but with a further increase in zinc-content the percentage loss of strength decreases again, being only 26 per cent. in alloy No. 26. This peculiarity of a maximum rate of loss of strength with increasing temperature is again found at 200° C. (392° F.). Alloys Nos. 9 and 26 both show a percentage loss of about 57 per cent., while this value rises up to 77 per cent. in alloy No. 17, the intermediate alloys on both sides of No. 17 showing values which, with slight irregularities, are intermediate. Although, therefore, the deterioration of properties with rising temperatures is very rapid in all these alloys as compared with steel or even with bronzes, yet the alloys richest in zinc are decidedly superior in this respect to the lower members of the series here studied. Even at 200° C. it must be noted that alloy No. 25 has still an ultimate stress of nearly 11 tons per square inch.

High Temperature Tensile Tests.

Fig. 93.—*Alloy No. 25.* Fig. 94.—*Alloy No. 26.*



Perhaps the most striking of all the figures obtained in these tensile tests at high temperatures are those for elongation. Thus alloy No. 20 at a temperature of 100° C. shows only 18 per cent.

of elongation on a 2-inch specimen; at 250° C. (482° F.) this has risen to 28·5 per cent., at 400° C. (752° F.) to 95 per cent. and at 595° C. (1,104° F.) to the amazing value of 130 per cent. The fracture of this alloy at high temperatures, and a number of similar ones showing high elongations, were found to be drawn down to very fine points, leaving each of the pieces with a smooth, conical, dome-shaped end resembling that of a modern projectile. The photograph, Plate 22, shows some examples of this form of fracture—a form which undoubtedly suggests extreme ductility. The authors were particularly surprised at these evidences of great ductility in the alloys at high temperatures, since not only are these alloys generally regarded as being excessively "tender" at high temperatures, but their own experience at the rolling-mills indicated clearly that above 400° C. these materials were too brittle to withstand the process of rolling into bars. It therefore occurred to the authors to inquire whether this extreme ductility under gradually and steadily applied tension might not be accompanied by brittleness to sudden shocks. For this purpose a series of small forging tests were made. Small pieces of the alloys were heated in a muffle to various temperatures, a small iron block being heated along with the specimens of the alloys. When the desired temperature for a given test was reached, the specimen of alloy was placed on the iron block (still in the muffle) and the two were then withdrawn together and placed on an anvil and immediately struck a smart blow with a 7-lb. hammer. With the harder alloys it was found that for temperatures up to 400° C. increasing malleability was obtained, but at 450° C. the disks cracked at the edges after repeated blows. At 500° C. the specimen broke up into coarse powder at the first blow. In this way it was possible to find a definite limit to the temperatures at which hot forging was possible, and these served as satisfactory guides for hot-rolling operations; yet at temperatures where the alloy was completely brittle, even to light blows, the tensile tests showed an exceptionally high degree of ductility. These observations are of some interest as they afford a very clear example of the fact that a tensile test will not necessarily reveal the presence of brittleness even when present to a very high degree.

Determination of the Elastic Properties of the Alloys.—These were studied in the same manner as the alloys described in the Ninth Report to the Alloys Research Committee. Tensile test-pieces of standard form, having a diameter of 0·5 inch and 8 inches between gauge marks, were prepared of alloys Nos. 5, 13, 15, 17, 20 and 26, the material used being hot-rolled bars $\frac{7}{8}$-inch diameter, a second series of the same alloys (except No. 26) being prepared from cold-drawn bars $\frac{13}{16}$-inch in diameter. Both series of specimens were tested for elastic modulus and elastic limit by means of the Ewing

FIG. 95.

Elasticity Observations on Hot-Rolled Bars.

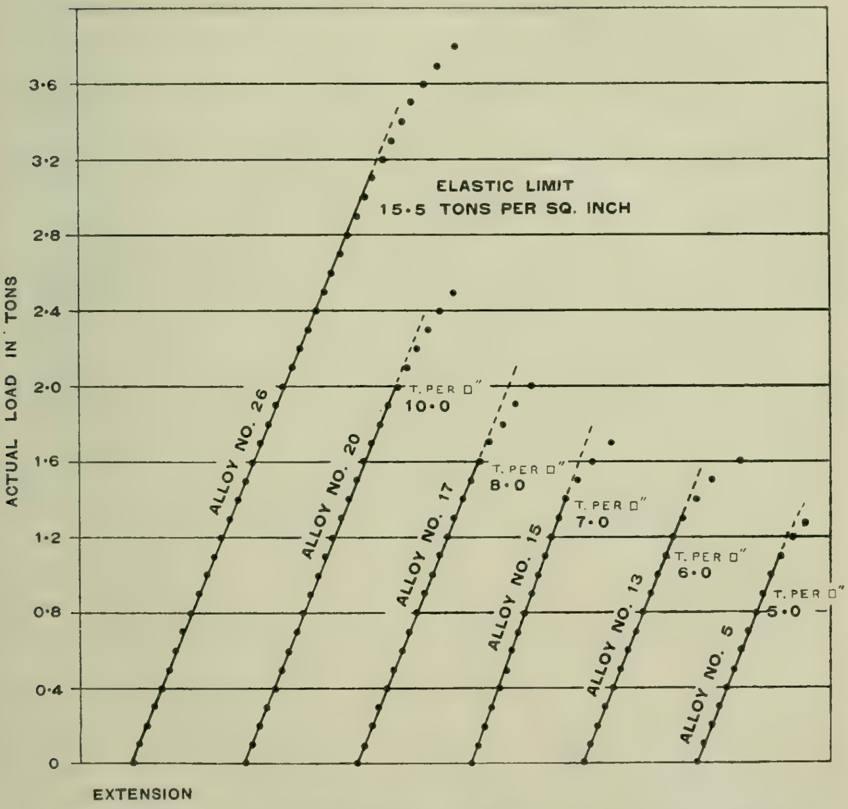


TABLE 45.

Elastic Properties of $\frac{7}{8}$-inch Hot-Rolled Bars.

No. of Alloy.	Elastic Limit.	Elastic Modulus.
	Tons per sq. in.	Lb. per sq. in.
5	5·0	$9{\cdot}06 \times 10^6$.
10	6·0	9·07 ,,
15	7·0	9·87 ,,
17	8·0	8·98 ,,
20	10·0	8·98 ,,
26	15·5	8·81 ,,

TABLE 46.

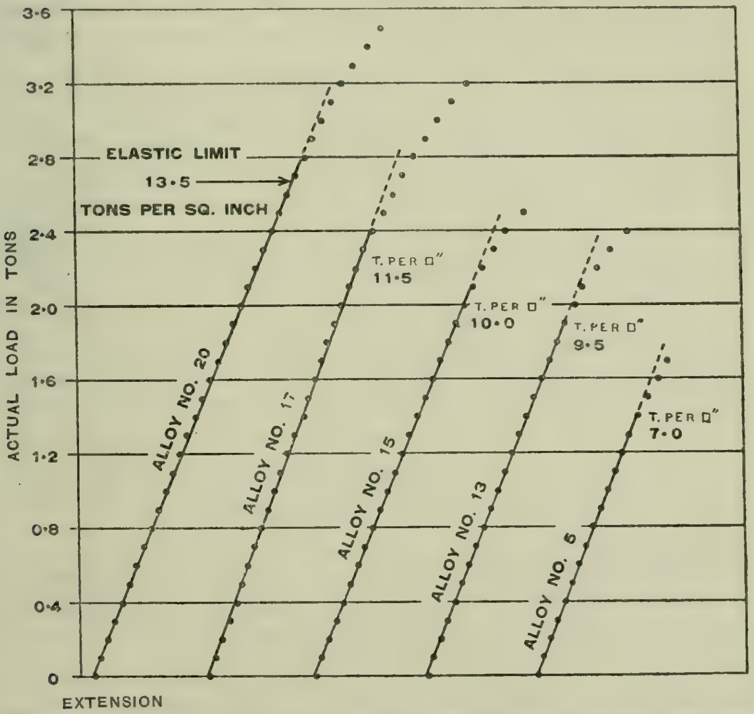
Elastic Properties of $\frac{13}{16}$-inch Cold-Drawn Bars.

No. of Alloy.	Elastic Limit.	Elastic Modulus.
	Tons per sq. in.	Lb. per sq. in.
5	6·5	$9{\cdot}07 \times 10^6$.
13	8·5	9·04 ,,
15	10·0	8·84 ,,
20	16·0	8·98 ,,

extensometer. The extensometer readings have not been tabulated, but the results have been plotted in Figs. 95 and 96, and the values calculated for elastic limit and elastic modulus in Tables 45 and 46 (page 418) referring to the hot-rolled and cold-drawn bars respectively. The alloys all exhibited a very definite and satisfactory elastic behaviour, giving definite and regular extensions until the elastic limit is reached. The elastic limits increase regularly with the zinc-content, but it is notable that the elastic moduli are practically constant throughout the series, as the almost parallel courses of the lines of elastic deflection indicate. The only exception to this rule which is at all marked is that of alloy No. 17 in the cold-drawn condition. It is interesting to note, however,

Fig. 96.

Elasticity Observations on Cold-Drawn Bars.



that the elastic limits of the alloys Nos. 17 and 20 have been considerably raised by cold-drawing, thus showing that the material really had been distinctly hardened by the cold work put upon it, in spite of the fact that in the case of No. 20 no increase in ultimate stress has been produced by the process.

From the point of view of the possible employment of these alloys for the moving parts of machines or other purposes where either elastic stiffness or period of vibration enters into the problem, it is unfortunate that their elastic moduli are decidedly low, all lying near the value 9×10^6, as compared with $10 \cdot 75$ and $10 \cdot 4 \times 10^6$ for the two aluminium-copper-manganese alloys described in the Ninth Report. On the other hand, the elastic limits of those alloys in the hot-rolled condition are only 7·15 tons per square inch, while in the present series values as high as 15·5 tons per square inch are found. Reference to Fig. 102 (page 430), which will be referred to in detail below, shows that the elastic limits as found by the extensometer are always lower than the yield-points as determined with dividers on 2-inch specimens, but this difference becomes very small for hot-rolled alloys containing from 10 to 15 per cent. of zinc, increasing on either side of this middle range. In the case of cold-drawn bars, the difference between elastic limit and yield-point increases steadily with increasing zinc-content, and consequently with increasing absolute values of both yield-stress and elastic limit.

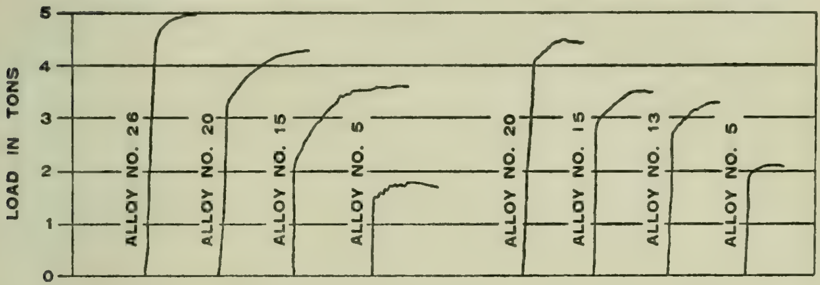
Autographic Stress-Strain Diagrams.—The 8-inch specimens which had been used for the extensometer observations, having only been carried very slightly beyond their elastic limits, were utilized for the preparation of autographic stress-strain diagrams, the apparatus used and mode of working being identical with that employed in connection with the two previous reports. The resulting diagrams are reproduced (from direct tracings) in Fig. 97 (page 421). It will be seen that in every case the yield-point is well marked, particularly in the hot-rolled bars. In some of the alloys the diagram, above the yield-point, shows a jagged or stepped appearance; this arises from the peculiar manner in which many of these alloys undergo plastic extension, that is, by a succession of more or less sudden yields. In the case of alloy No. 5 cold-drawn no less than seven of these steps can be counted.

The ultimate stresses, yield-points, and elongations as observed on these 8-inch specimens are given in Table 47, where for purposes of comparison they are placed side by side with the results of tests on 2-inch specimens of the same materials.

Fig. 97.

Autographic Stress-Strain Diagrams.

Alloys as Hot-Rolled to $\frac{7}{8}$ inch. Alloys Cold-Drawn to $\frac{13}{16}$ inch.



Reference to this Table shows that the two series of tests are in exceptionally good agreement; the elongations are, of course,

TABLE 47.

Comparison of Yield-Point, Ultimate Stress and Elongation on 8-inch and 2-inch Specimens in Hot-Rolled Condition.

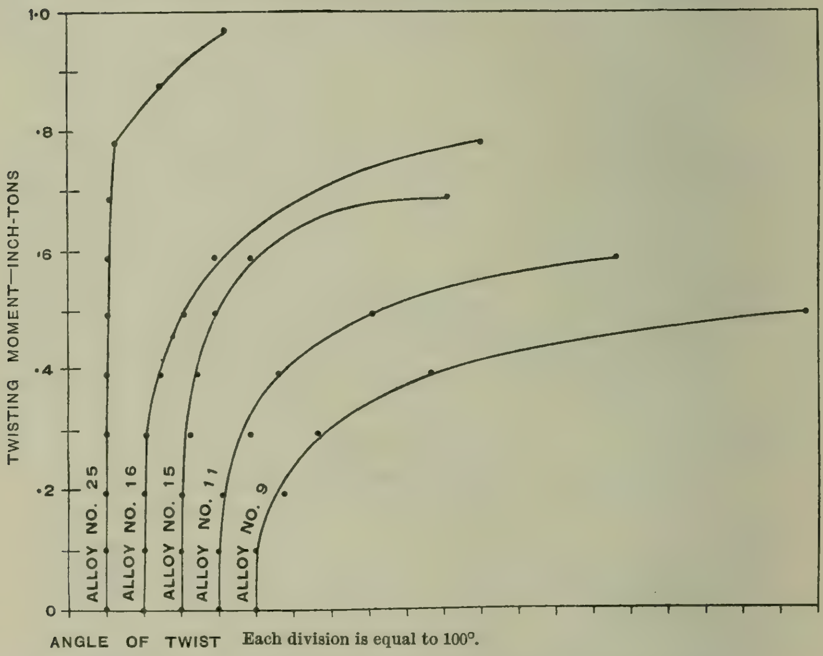
No. of Alloy.	Yield-Point.		Ultimate Stress.		Elongation.	
	Tons per sq. in.		Tons per sq. in.		Per cent.	
	On 8-inch.	On 2-inch.	On 8-inch.	On 2-inch.	On 8-inch.	On 2-inch.
5	7·5	7·4	8·22	8·94	10·68	26
15	9·3	8·6	16·95	16·54	18·60	29·5
20	16·43	12·40*	21·30	21·40	15·30	25
26	21·79	15·70†	24·45	23·86	7·0	20

* Mean of 10·36 and 14·40. † Mean of 11·40 and 20.

smaller on the 8-inch specimens, but the difference is not abnormal except in the case of alloy No. 5, where the 8-inch specimen shows an unduly low extension. The ultimate stresses of the two series are in agreement almost within the limits of experimental error, but it is remarkable that in two cases the 8-inch specimen gives the higher result. This comparison serves to establish the complete reliability of the tests made on 2-inch specimens, and also serves to justify the practice of using the highest value obtained by repeated tests on the same alloy. In regard to yield-stresses there is rather more divergence between the two series, but here again 8-inch specimens give the higher values.

FIG. 98.

Torsion Tests on Specimens cut from Rolled Bars 1¼-inch diameter.



Each division is equal to 100°.

Torsion Tests.—Torsion tests were made on a series of specimens cut from hot-rolled bars 1¼-inch in diameter; the shape and size of the specimens, as well as the method of making the tests, were the same as that employed in connection with the Eighth and Ninth Reports. Alloys Nos. 9, 11, 15, 16 and 25 have been tested in this way and the actual observations are plotted in the diagram of Fig. 98 (page 422), while the corresponding data with the calculated maximum stresses are given in Table 48.

The comparison of the maximum stresses found in tension and in torsion on the same materials is tabulated in Table 49 (page 424). The ratio of these maximum stresses given in the last column of that Table is interesting, as it shows a steady decrease of the ratio with the increase of zinc-content; in other words, the torsional strength does not increase as rapidly with increasing zinc-content as does the tensile strength. The comparison of torsional and tensional maximum stresses is also shown graphically in Fig. 99 (page 424).

TABLE 48.

Torsion Tests.

Diameter, 0·624 inch. Length, 3 inches.

No. of Alloy.	Maximum Load.		Total Twist.	
	Twisting Moment.	Calculated Maximum Stress.	Number of Turns.	Angle of Twist.
	Inch-tons.	Tons per sq. in.		Degrees.
9	0·4925	10·32	4·07	1467
11	0·595	12·39	2·94	1059
15	0·6895	14·46	1·98	712·5
16	0·788	16·52	2·58	928·5
25	0·985	20·65	0·86	310·5

Fig. 99.

Comparison of Maximum Stresses found in Tension and in Torsion.

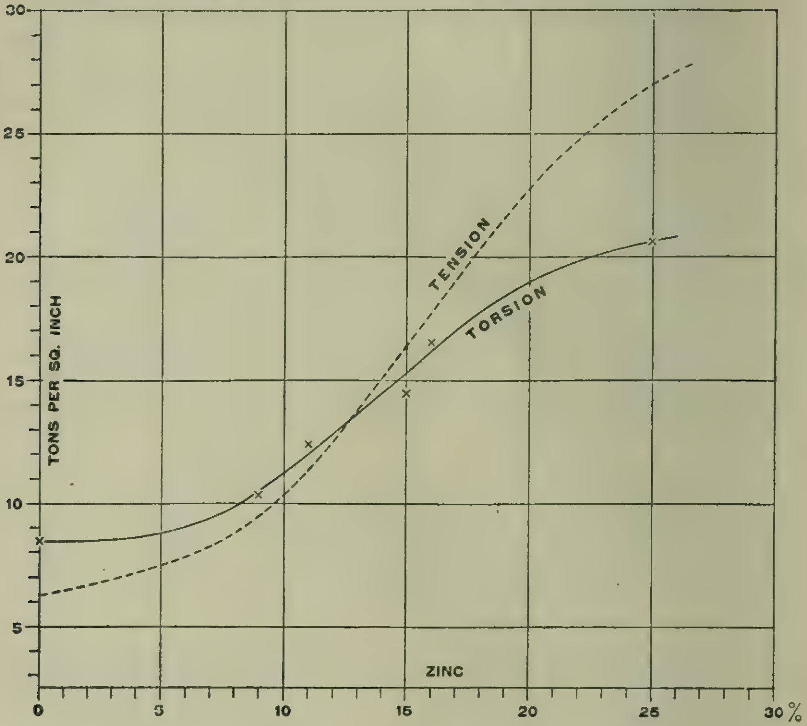


TABLE 49.

Comparison of Maximum Stresses found in Torsion and in Tension.

No. of Alloy.	Maximum Stress in Tons per square inch.		Ratio $\frac{\text{Torsion.}}{\text{Tension.}}$
	Tension.	Torsion.	
9	9·41	10·32	1·10
11	11·40	12·39	1·09
15	16·38	14·46	0·88
16	17·75	16·52	0·93
25	27·09	20·65	0·76

Since no torsion tests on light alloys were included in either the Eighth or Ninth Reports, comparison with other alloys in this respect is not possible, but, as compared with other materials of much higher specific gravity, the result of alloy No. 25, giving a maximum stress of 20 tons per square inch with an angle of twist of 310°, is remarkably good.

Hardness Numbers.—The hardness numbers of the alloys, in the form of sections cut from the 1¼-inch hot-rolled bars, have been determined both by the Brinell and Scleroscope methods. The determinations have been made in the same manner as that described in previous Reports, and the hardness numbers have been calculated by the same formulæ, loads of 1,000 kg. and 3,000 kg. being used. The diameters of the indentations and the calculated Brinell numbers are given in Table 50, where the Scleroscope readings are also tabulated. These results are shown graphically in Fig. 100 (page 426), where the Brinell numbers obtained with a load of 1,000 kg. are represented by crosses, those obtained with a load of 3,000 kg. by dots, and the Scleroscope readings by small circles. The crosses and dots are distributed fairly evenly about a single straight line which represents the average Brinell hardness with reasonable closeness, although, if a single very divergent observation is neglected, a slightly curved

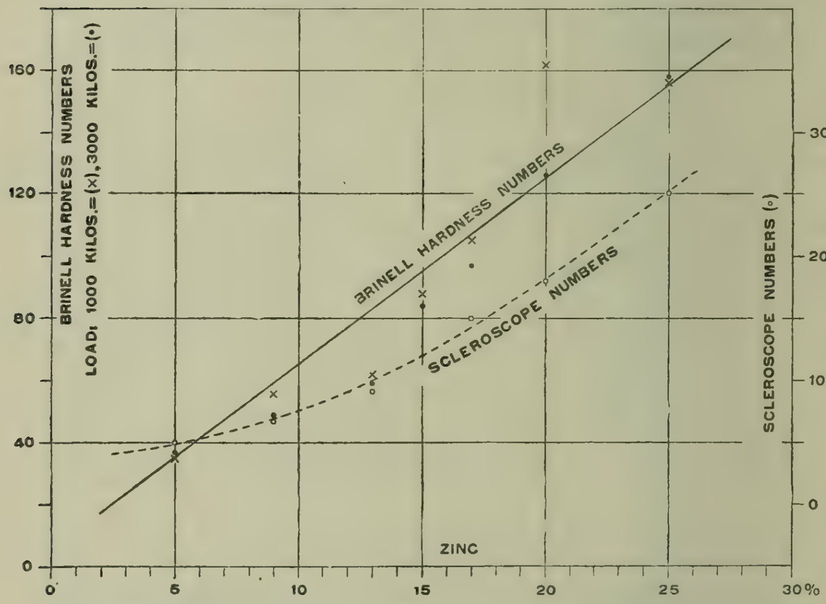
TABLE 50.

No. of Alloy.	Load of 1,000 kg. (2,204 lb.)		Load of 3,000 kg. (6,613 lb.)		Scleroscope No.
	Diameter of Indentation.	Hardness No. Brinell.	Diameter of Indentation.	Hardness. No. Brinell.	
5	5·564	35	9·305	37	5·0
9	5·306	56	8·665	49	6·7
13	4·996	62	8·180	59	9·1
15	4·296	88	7·166	84	—
17	3·942	105	6·749	97	15·0
20	3·189	162	6·051	126	18·0
25	3·284	156	5·471	158	25·0

line, convex downwards, would represent the results more accurately. The Scleroscope readings lie well on such a slightly curved line, but they do not run proportionately to the Brinell numbers. Neither of these curves of hardness numbers shows the double curvature found in the tensile strength curves, so that it is evident that in these alloys tensile strength and hardness are not strictly proportional to one another, although in a broad sense the usual relation still holds.

Fig. 100.

Hardness Tests on Bars $1\frac{1}{4}$-inch diameter.



Compression Tests have been carried out on a representative series of alloys (Nos. 9, 11, 15, 16, 19 and 25) in precisely the same manner as that described above in connection with compression tests on the alloys in the cast state, except that in the present series the specimens were machined from the material in the form of hot-rolled bars $\frac{7}{8}$-inch in diameter. The values obtained are

FIG. 101.

Compression Tests on Hot-Rolled Bars ⅞-inch diameter.

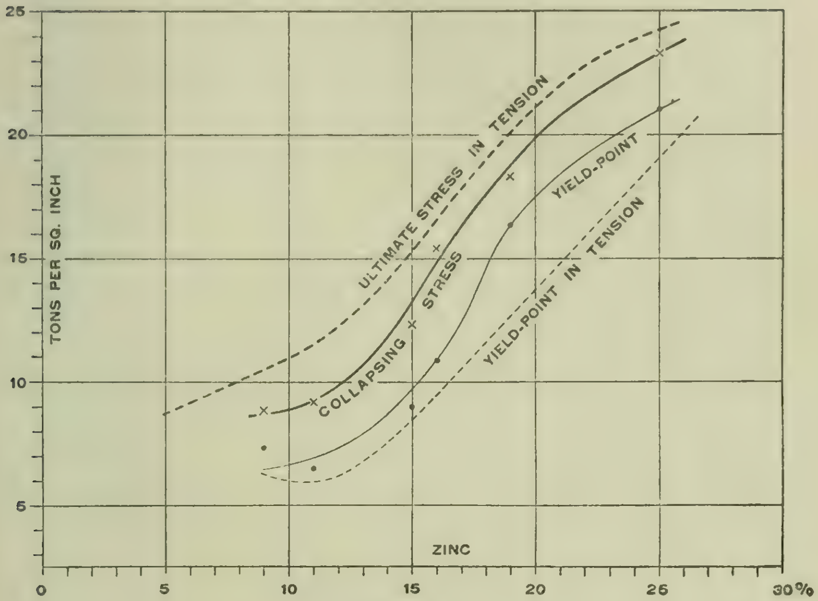


TABLE 51.

Compression Tests.

(Wrought Material. Hot-Rolled Bars ⅞-inch diameter.)

No. of Alloy.	Yield-Point.	Collapsing Stress.
	Tons per sq. in.	Tons per sq. in.
9	7·32	8·86
11	6·50	9·21
15	9·06	12·33
16	10·81	15·43
19	16·34	18·31
25	21·07	23·31

given in Table 51 and are shown graphically in Fig. 101, where both the observed yield-points and collapsing stresses are represented. For purposes of comparison, the curves of yield-point and ultimate stress as obtained from tensile tests on the same alloys in the same condition (*see* Table 12, page 373, and

Fig. 54, page 374) are shown on Fig. 101 along with the curves for compression tests. In general terms the shape of the compression curves is very similar to that of the curves of tensile results, showing that the compressive strength depends upon zinc-content in much the same manner as does the tensile strength. On the other hand, it is interesting to note that the yield-points in compression are uniformly higher than those for tension. In view of the fact that the microstructures of these alloys all exhibit decided signs of deformation of the crystals in the direction of rolling, one would have been led to anticipate the contrary result. The "collapsing stress," as shown by the full-line curve of Fig. 101, lies slightly but consistently below the ultimate stress curve from the tension experiments; the two curves, however, lie so close together that it would appear that the collapsing stress as observed in these experiments is closely related to the ultimate tensile strength. In general terms, it is evident from these compression tests that the behaviour of the alloys under compression is perfectly consistent with their behaviour under tension.

Dynamic Tests.—Two classes of dynamic tests were made on a number of the alloys of the present series; the first class were carried out under the direction of Dr. T. E. Stanton in the Engineering Department of the National Physical Laboratory on the machines specially designed for that purpose, while the second class were carried out by Professor J. O. Arnold on his well-known alternate-bending testing machine at the University of Sheffield. Not only are the results of these tests of some interest in themselves, but a series of such tests carried out on a group of alloys of gradually varying composition affords an interesting means of forming a judgment as to the interpretations to be put on the results of the tests employed. The relative "merit" or value of the various tests can of course only be determined by finding, as the result of practical experience with those alloys, which of the tests best represents their behaviour in various practical circumstances; all that the present comparison can hope to accomplish is a correlation of the various forms of test

TABLE 52.

Alternating-Stress Tests.

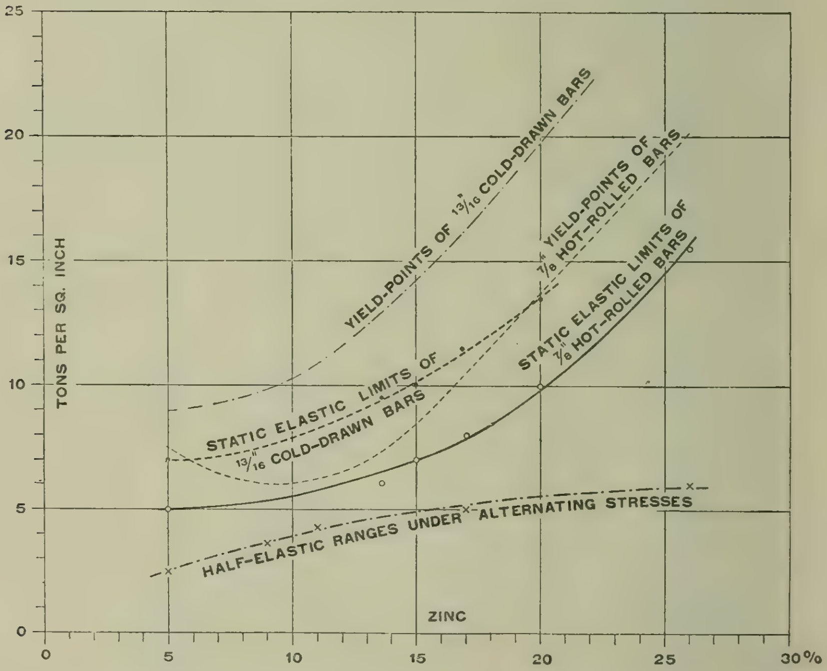
No. of Alloy.	No. of Specimen.	Range of Stress.	Number of Reversals for Fracture.	Maximum Safe Range of Stress.
		Tons per sq. in.		Tons per sq. in.
5	1	5·68	114,000	5·0
	2	5·46	157,000	
	3	5·04	1,007,100	
9	1	8·76	34,500	6·7
	2	7·05	347,000	
	3	6·55	1,000,000 (unbroken)	
11	1	8·80	246,600	8·6
	2	8·55	496,300	
	3	7·92	872,300	
	4	7·16	1,000,000 (unbroken)	
17	1	12·41	37,400	10·0
	2	10·98	445,100	
	3	10·45	632.800	
26	1	14·05	86,400	12·0
	2	12·40	756,200	
	3	11·73	1,060,000 (unbroken)	

among themselves. All the dynamic tests have been carried out on the same machines and in the same manner as those described in the Ninth Report, so that detailed descriptions of these are not necessary here.

Alternating-Stress Tests were carried out on Dr. Stanton's machine at the rate of 1,080 reversals per minute. The observed numbers of reversal for fracture at various ranges of stress are given in Table 52 (page 429), while in the last column of that Table are given the safe ranges of alternating stress calculated for each alloy from these observations. These range from 5 tons per square inch in the case of alloy No. 5 up to 12 tons per square inch in

FIG. 102.

Comparison of Elastic Limits and Yield-points.



No. 26. With these figures we may compare those obtained for the best of the aluminium-copper-manganese light alloys (*see* Ninth Report, page 271), which gave a safe range of 9·4 tons. The present alloys therefore afford a decided advance on the best of the earlier alloys, but this advance is not as considerable as might have been anticipated from a comparison of the yield-points of the alloys concerned. The comparison of the safe ranges of alternating-stress with the yield-points and elastic limits as determined under "static" tension is shown in Fig. 102 (page 430). The alternating-stress curve lies very considerably below the static elastic limit, a fact which suggests that the static yield-points are, to some extent, artificially raised by cold working of the material. It is interesting to notice also that while all the curves relating to static tests on Fig. 102 are convex to the axis of composition, the alternating-stress curve is slightly concave to that axis. In this respect it resembles the curve of single-blow impact tests, and to a lesser extent, the curve representing the results of Professor Arnold's alternate-bending tests (*see* Figs. 103 and 104). This fact suggests that failure under the alternating-stress test is in some way affected by the ductility of the material.

Alternate-Bending Impact Tests.—These were carried out in two series, with the tup falling 1 inch and 0·71 inch respectively. The results of these tests are given in Table 53 (page 432) and they are plotted in Fig. 103. Under both series of tests the higher members of this series of alloys exhibit a resistance to this test which is strictly proportional to their zinc-content, and the actual values attained are high compared with those given by other light alloys. The tests made with a height of fall of 0·71 inch are exactly comparable with those described in the Ninth Report (*see* page 272) on two light alloys of aluminium with copper and manganese; the highest result there obtained is 672 blows, while in the present series this result is almost matched by alloy No. 9 with 567 blows, while the best of the present series (No. 26) requires over five times that number of blows to break it. The authors regard this result as being

TABLE 53.

Repeated-Bending Impact Tests.

No. of Alloy.	Weight of Striking Tup.	No. of Blows for Fracture.	
		Height of Fall 0·71 inch.	Height of Fall 1·0 inch.
	Lb.		
5	4·71	441	229
9	,,	567	269
13	,,	—	474
15	,,	1441	599
17	,,	1706	669
20	,,	2277	933
26	,,	3404	1502

Fig. 103.

Repeated-Bending Impact Tests.

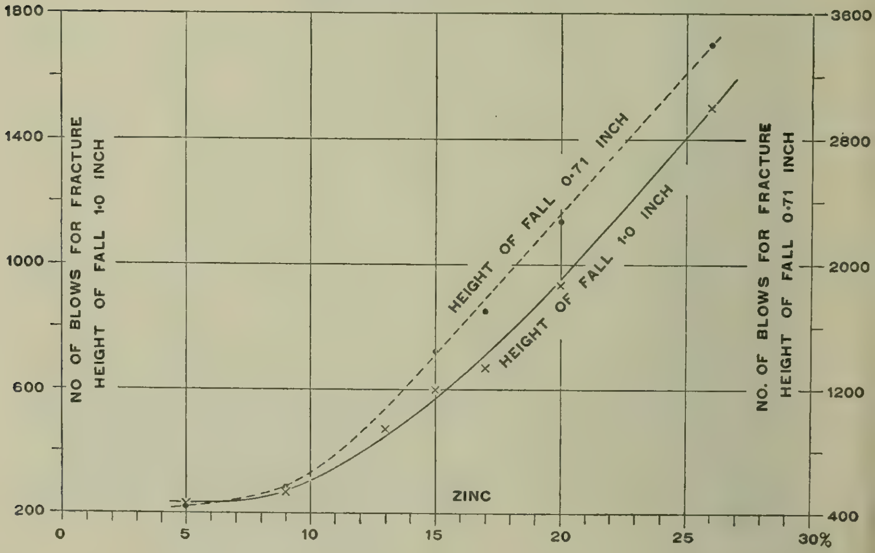


TABLE 54.

Single-Blow Impact Tests (Izod).

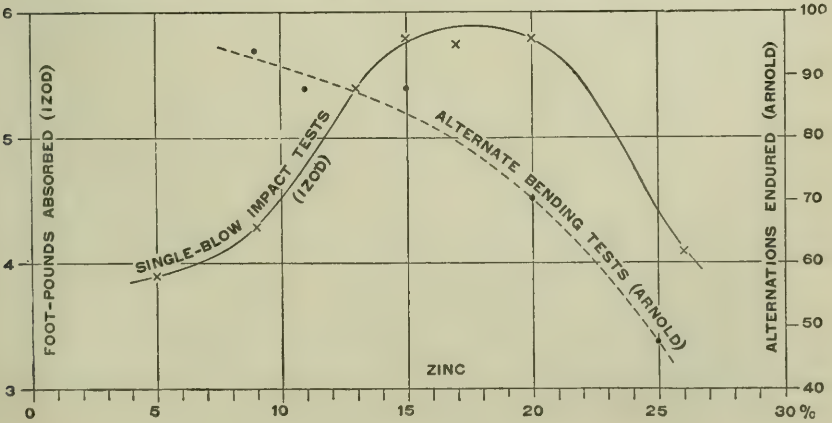
No. of Alloy.	Foot-pounds Absorbed.	Mean.
5	4·00 3·80	3·9
9	4·25 4·30	4·3
13	5·70 5·10	5·4
15	5·85 5·75	5·8
17	5·80 5·70	5·75
20	5·75 5·85	5·8
26	4·60 3·50	4·1

remarkable, particularly in view of the widely-expressed opinion that aluminium-zinc alloys are weak under shock.

Single-Blow Impact Tests (*Izod Machine*).—These tests, like all the other dynamic tests described in the present section, were

Fig. 104.

Single-Blow Impact Tests (Izod), *and Alternate-Bending Tests* (Arnold).



carried out on specimens cut from hot-rolled bars $\frac{7}{8}$-inch diameter. It should be noted that these bars do not in all cases represent the alloys in their best form, so far as tensile tests are concerned, so that possibly these dynamic tests also do not do full justice to the materials. The results of the Izod single-blow tests are given in Table 54 (page 433), and they are plotted in the full-line curve of Fig. 104. A comparison of this Table with that on page 271 of the Ninth Report, referring to similar tests on the light alloys of that series, shows that the present alloys, or rather the best members of the present series, are definitely although only slightly superior to the earlier alloys. That the superiority is not more marked is due to the falling off in regard to this test which occurs after the concentration of 20 per cent. of zinc is passed. This test, it appears, takes account both of the tensile strength *and* the ductility of the alloys, since the highest results are obtained for those alloys having a considerable tensile strength combined with considerable ductility; a further increase of zinc, accompanied by a rise in tensile strength and a decrease in ductility, produces a lower result under the single-blow impact test.

Professor Arnold's Alternate-Bending Tests.—These tests were carried out by the kindness of Professor J. O. Arnold on his special machine at the University of Sheffield. The size of specimens used and the setting of the machine were precisely similar to those employed in connection with the Ninth Report. The results of Professor Arnold's tests as reported by him are given in Table 55, and the means of the results are plotted in the dotted curve of Fig. 104 (page 433). With regard to these results Professor Arnold remarks:—"The texture of the alloys as evidenced by line of final fracture was on the whole remarkably even, the final rupture taking place in almost every case in a line coincident with the horizontal zero of stress on the plane of maximum stress. The capacity of the alloys to resist rupture in alternation under the conditions named varies from $\frac{1}{8}$ to $\frac{1}{4}$ that of heat-treated best mild structural steel."

As tests of this description were not carried out on the light alloys described in the Eighth and Ninth Reports, a comparison is not available.

A comparison of the results of the various dynamic tests which have just been described affords considerable interest. Thus if we turn to Fig. 54 (page 374), representing the ordinary tensile tests on

TABLE 55.

Professor Arnold's Alternate-Bending Tests.

No. of Alloy.		Alternations Endured.			
		1st Test.	2nd Test.	Mean of Two.	Mean of Four.
9	(*a*)	90	110	100	—
	(*b*)	86	90	88	94
11	(*a*)	80	90	85	—
	(*b*)	88	94	91	88
15	(*a*)	78	94	86	—
	(*b*)	90	90	90	88
20	(*a*)	70	74	72	—
	(*b*)	70	68	69	70·5
25	(*a*)	52	52	52	—
	(*b*)	42	44	43	47·5

the same material as that used for the dynamic tests, we find first that the curves given by the repeated-bending impact test of Dr. Stanton are practically parallel to the curves for tensile strength and yield-point, so that apparently ductility does not enter into this test at all. On the other hand, the curve representing Professor Arnold's results is similar in type to the curves of ductility as represented by the reduction of area and elongation under tensile test—a fact which suggests that for the purpose of Professor Arnold's test, so far as these alloys are concerned at all events, ductility is the most important factor. Finally, the single-blow impact test, as already pointed out, gives a curve approximately representing the sum of ultimate stress and elongation—the curves of the repeated-bending impact tests and of Professor Arnold's tests might be added up to give a resultant curve very similar to that of the single-blow impact test. Taking all the tests together, the general conclusion seems to be justified that the alloy containing 20 per cent. of zinc is the most promising member of the series.

Corrosion Tests.—The corrosion tests which are sufficiently completed to be described in the present Report consist in exposure of cast specimens of the alloys to the sea for a prolonged period, the loss of weight of each plate being observed at regular intervals. The results of these tests are regarded by the authors as being entirely of a preliminary character, particularly for two reasons. The first of these is that the specimens employed were small sand- and chill- castings, merely machined to the desired size and shape. The study of the alloys undertaken since these corrosion tests were begun has demonstrated the complexity of structure of the alloys in this condition as compared with the perfectly homogeneous structure which is readily obtained by prolonged annealing. It is evident therefore that the best results as regards resistance to corrosion will be obtained by the use of annealed material (either cast or wrought). As soon as this conclusion was realized by the authors, a fresh set of test-pieces were prepared of annealed castings, but these have not yet been immersed in the sea long enough to allow conclusions to be drawn.

A further reason for distrusting to some extent the results of the corrosion tests described below is that the measurement of corrosion has been made only in terms of loss of weight. After a sufficient length of time, when corrosion has gone on to a considerable extent, it is very probable that the loss of weight is a correct measure of the amount of corrosion, particularly if care is taken to remove all adhering non-metallic matter as far as possible.

In the earlier stages of corrosion, however, it is probable that loss of weight may not represent the amount of corrosion, and accordingly the authors have contemplated a series of tests in which loss of strength should be used as a measure of corrosion; but it is not easy to devise a really satisfactory method of making such tests, and the authors have not been able to include them in the present Report.

The specimens employed for the corrosion tests by exposure to the sea were small castings measuring 3 inches by 4 inches and about $\frac{3}{8}$-inch thick; these were machined to square plates, $2\frac{3}{4}$ inches wide and $\frac{1}{4}$-inch thick, with two circular holes $\frac{1}{4}$-inch diameter in two opposite corners. These were first framed very loosely in teak, in the manner previously adopted with the alloys of copper with aluminium and manganese, but it was found that where the alloys were in contact with the wood local corrosion was set up. The specimens were then attached to an open teak frame by means of cords previously soaked in Stockholm tar, and this method gave better results, but it became evident that the friction of the suspending cords led to increased local corrosion at the two corners near the holes. Finally the specimens were fixed to teak boards by means of screws passing through the $\frac{1}{4}$-inch holes, but the metal of the screws is completely insulated from the alloy specimens by means of an interposed ferrule or short tube of glass; the specimens are kept in position, and out of contact with either the screw-heads or the boards by means of small porcelain insulators pushed on to the screws both above and below the specimen plates. A photograph of the boards with the specimens arranged in this way is shown on Fig. 105, Plate 21.

By the courtesy of the Lords of the Admiralty and the Authorities of Portsmouth Dockyard, the boards with their attached specimens have been suspended in the sea under one of the jetties of Portsmouth Dockyard, and they have been removed to the Laboratory and cleaned and weighed at intervals of three months. Up to the last weighing recorded in this Report the total time of immersion was 521 days.

FIG. 106.

Corrosion Tests. Sand- and Chill-Castings.

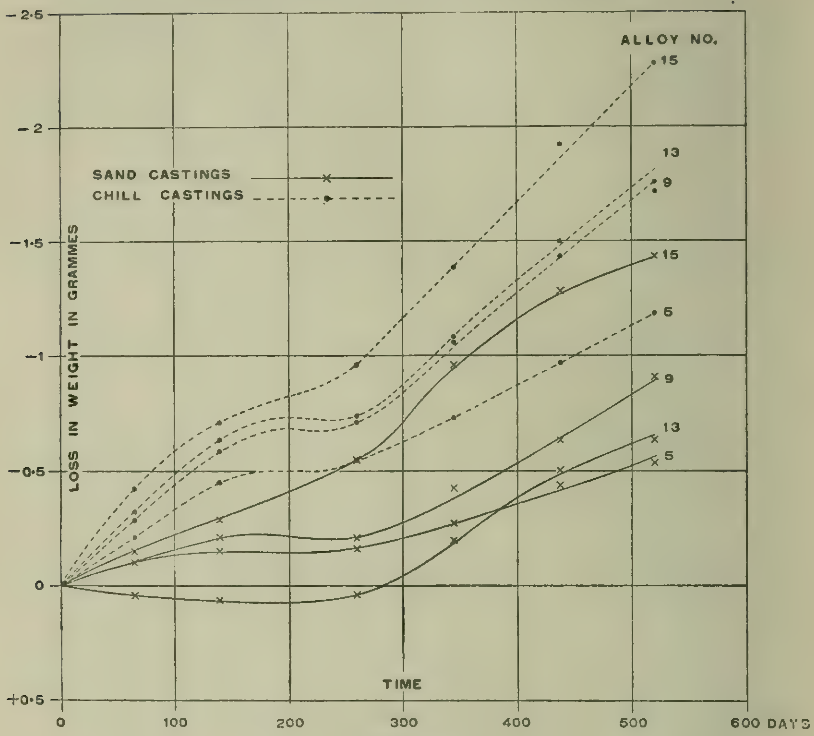


TABLE 56.

Corrosion Tests.

No. of Alloy.	Loss of Weight per cent. per month of 30 days.		Loss of Weight in lb. per sq. ft. per month of 30 days.	
	Sand.	Chill.	Sand.	Chill.
5	0·0371	0·0812	0·00054	0·0012
9	0·0606	0·1148	0·00092	0·0017
13	0·0429	0·1127	0·00065	0·0018
15	0·0923	0·1489	0·00145	0·0023

The actual observations of loss of weight are plotted in Fig. 106 (page 438), the sand-castings being shown in full lines, while the dotted lines represent the chill-castings. The average rates of corrosion as calculated from these observations, and expressed in terms of loss of weight per cent. per month of 30 days, and also in terms of loss in lb. per square foot per month of 30 days, are given in Table 56 (page 438). The first striking fact about this Table is the superiority of the sand-castings over the chill-castings from the point of view of corrosion. This is of course readily understood from the microstructures, which are less homogeneous in the chill than in the sand-castings. The anticipation that annealed castings will give still better results is thus borne out by the present results. Next we find that, with one or two minor exceptions, the rate of corrosion increases with increasing zinc-content. As regards the actual rate of corrosion as indicated by these figures, the loss of weight per square foot per month is closely comparable with that previously found for such alloys as Naval Brass and Muntz Metal. Thus in Table 68 of the Ninth Report (page 289) we find that Muntz Metal loses at the rate of 0·0023 lb. and Naval Brass at a rate of 0·00124 lb. per square foot per month ; in Table 56 we find that the chill-casting of alloy No. 5 gives the same figure as that just quoted for Naval Brass, while alloy No. 15 gives the same figure as Muntz Metal, while the sand-castings show a rate of loss of about one-half of these figures. It must, however, be borne in mind that these alloys are of much lower specific gravity than brass, so that the same loss of weight represents the removal of a much larger bulk of metal. Making the necessary allowance for this difference in density, it appears that the sand-castings of the present alloys lose by corrosion at a rate which varies from one-and-a-half times that of Naval Brass to one-and-a-half times that of Muntz Metal, according to their zinc-content. In view of the fact that direct exposure to the sea constitutes extremely severe treatment for alloys of this kind, these figures are to be regarded as fairly satisfactory, particularly as the effects of the suspending cords, alluded to above, are included in the present series of results.

Conclusion.—The authors desire to record their indebtedness to all those who have aided them in carrying out the work described in this Report. In the first place their thanks are due to the British Aluminium Co., and especially to Mr. W. Murray Morrison and to Mr. J. Lawrence. The British Aluminium Co. have not only supplied the considerable quantities of the purest commercial aluminium which has been used in the preparation of the alloys, but they have also allowed the authors to use their rolling-mill and plant on no less than four occasions for the purpose of rolling and drawing the alloys into the various forms required. Without the very cordial co-operation of the company and of the gentlemen named, the carrying out of the present research would have been rendered exceedingly difficult if not altogether impossible.

The thanks of the authors are also due in a special degree to Sir John Brunner, Bart., who presented the quantity of very pure zinc which has been used in the production of the alloys. The high purity of this zinc has proved to be of great importance, and the authors have reason to believe that their favourable results, particularly as regards corrosion, are principally due to the purity of the zinc employed.

In connection with the corrosion tests at Portsmouth, continued by the kind permission accorded by the Lords of the Admiralty to the Alloys Research Committee, the authors are personally indebted for the assistance and courtesy received from the Dockyard officials, particularly from the Manager of the Construction Department.

Finally, the authors are indebted to the Director of the National Physical Laboratory, Dr. R. T. Glazebrook, C.B., F.R.S., for his continued interest in the Research. They also desire to express their thanks for the co-operation of many members of the Scientific Staff of the Laboratory, notably to Dr. Stanton and Mr. Jakeman in connection with the dynamic tests and the preparation of the many test-pieces, and to Mr. D. Ewen for assistance with the laborious series of tests at high temperatures, and to Mr. L. L.

Bircumshaw for many of the chemical analyses quoted throughout the Report.

The Report is illustrated by Plates 9 to 22 and 42 Figs. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

The Properties of a Ternary Alloy of Aluminium with Zinc and Copper.—As already stated in the body of the Report, the study of the ternary alloys of aluminium with zinc and copper has to a considerable extent been carried out along with the investigations described in the present Paper, but this work is of such large dimensions that it has not yet been carried far enough to allow a systematic account of these ternary alloys to be included in the present Report. On the other hand, the results of tests on one of these alloys are of so promising a character that the authors have thought it desirable to give a brief account of them in the present Appendix rather than allow them to remain unpublished until the next complete Report can be presented.

The alloy which, so far as the experiments have yet been carried, has given the most remarkable results among those obtainable by means of the light ternary alloys of aluminium with zinc and copper is one consisting approximately of 25 per cent. of zinc, 3 per cent. of copper and 72 per cent. of aluminium. A summary of the tensile tests carried out on this alloy is given in Table 57 (pages 442–3). In the cast state the alloy shows little or no ductility, but the tensile strength is 18·25 and 20·22 tons per square inch in the sand- and chill-castings respectively. The hot-rolling of this alloy is, with the plant and methods employed for aluminium, a matter of some difficulty, but the authors have several times succeeded in obtaining perfectly sound bars, and they are convinced that the alloy could be rolled commercially with suitable means. Great care in temperature regulation is, however, required; if slightly too hot the alloy breaks up into powder, while if too cold it becomes excessively hard. The rolled alloy exhibits considerable ductility,

TABLE 57.

Summary of Tensile Tests on Alloy No. 25/3.

Condition.	Yield-Point.	Maximum Stress.	Elastic Ratio.	Elongation on 2 inches.	Reduction of Area.
	Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
Sand-casting	5·71	18·25	0·31	2	—
Sand-casting annealed for 1 hour at 400° C.	15·31	17·25	0·88	2	—
Chill-casting	5·63	20·22	0·22	3·5	—
$1\frac{1}{4}$-inch hot-rolled bar	22·09	27·92	0·79	4	8·3
1-inch hot-rolled bar	22·09	30·83	0·71	16·5	24·5
$\frac{7}{8}$-inch hot-rolled bar	21·76	30·91	0·70	16·75	27·4
$\frac{7}{8}$-inch hot-rolled bar heated to 500° C. and quenched	17·52	28·87	0·60	16	36·4
$\frac{7}{8}$-inch hot-rolled bar heated to 500° C. and slowly cooled	14·76	27·92	0·52	22	21·4
$\frac{7}{8}$-inch hot-rolled bar heated to 400° C. and slowly cooled	18·71	27·64	0·67	19	30·5
$\frac{7}{8}$-inch hot-rolled bar heated to 300° C. and slowly cooled	16·14	26·23	0·61	24	39·1

⅞-inch hot-rolled bar heated to 200° C. and slowly cooled	16·14	26·15	0·61	23	47·2
½-inch hot-rolled bar	27·17	31·70	0·85	*21	38·47
½-inch hot-rolled bar annealed	18·61	24·41	0·76	*24	42·41
$\frac{7}{16}$-inch bar cold-drawn from ½-inch	25·76	32·76	0·76	11	—
$\frac{7}{16}$-inch bar cold-drawn from ½-inch, annealed	15·46	†23·30	0·66	18·5	—
⅜-inch cold-drawn from ½-inch	31·53	33·34	0·94	13	—
⅜-inch bar cold-drawn from ½-inch, annealed	16·21	23·60	0·64	19·5	—
Sheet 0·156-inch thick, longitudinal	20·95	27·96	0·74	6	—
Sheet 0·156-inch thick, longitudinal, annealed	16·03	23·40	0·68	18	—
Sheet 0·156-inch thick, transverse	none noticed	24·27	—	1	—
Sheet 0·156-inch thick, transverse, annealed	18·30	20·51	0·89	4	—
Sheet 0·075-inch thick, longitudinal	none noticed	23·90	—	1	—
Sheet 0·075-inch thick, longitudinal, annealed	14·05	22·57	0·62	6	—
Sheet 0·075-inch thick, transverse	none noticed	26·52	—	1	—
Sheet 0·075-inch thick, transverse, annealed	14·18	22·30	0·63	4	—

* On 1 inch.

† Split longitudinally at fracture.

but it could not be drawn into wire; the thinnest section obtained had a diameter of $\frac{3}{8}$-inch. Perhaps the most striking figure obtained from this alloy is the tensile test on the $\frac{1}{2}$-inch hot-rolled bar. This showed a yield-stress of 27 tons per square inch, an ultimate stress of 31·7 tons per square inch and an elongation of 21 per cent. (measured on 1 inch). By cold-drawing this material down to $\frac{3}{8}$-inch diameter, the yield-stress is further raised to 31·5 tons per square inch and the ultimate stress to 33·3 tons, while the elongation is reduced to 13 per cent. The specific gravity of this alloy in the condition just referred to is 3·29 grammes per cubic centimetre, and this gives a specific tenacity (as defined in the body of the Report) of 279 as compared with the value of 231 for the best of the binary alloys.

A photomicrograph, showing the homogeneous polyhedral structure as obtained when the rolled material has been annealed, is shown in Fig. 107, Plate 21.

As regards other tests, corresponding with some of those described and discussed in the body of the present Report, the alloy No. 25/3 gave the following results:—

Compression Test.—Yield-point 24·21 tons per square inch. Collapsing-stress 29·02 tons per square inch.

Dynamic Tests.—In direct alternation, the safe range was found to be 14 tons per square inch.

The repeated-bending impact test showed that with the standard tup and a height of fall of 0·71 inch the alloy required 4,525 blows for fracture (as compared with 3,404 blows required by the best of the binary alloys).

In the single-blow impact test (Izod) this alloy absorbed 1·7 foot-pounds. This compares unfavourably with the binary alloys, but is in accordance with the greater stiffness and lower ductility of the ternary alloy.

Under Professor Arnold's test this alloy endured 40 reversals, as compared with 47 for the strongest of the binary alloys.

Further tests on this alloy are not yet available, but it is hoped to give a fuller account of its properties when the systematic study of the whole group of ternary alloys has been carried out. Meanwhile it is hoped that the figures given above and in Table 57 will be sufficient to direct attention to what appears to be a promising material.

Discussion on Friday, 19*th April* 1912.

The PRESIDENT proposed a cordial vote of thanks to the authors for their very valuable account of an extremely useful research. He was sure the Members would agree with him that there had been nothing in the researches of the past which seemed to promise more practical and greater results than those dealt with in the Report. He also wished to compliment Dr. Rosenhain, who was a past master in the art, on the very clear and lucid way in which he had presented such an abstruse subject, and he was sure the Members had all extremely enjoyed his exposition.

The Resolution of thanks was passed by acclamation.

Sir WILLIAM H. WHITE, K.C.B. (Past-President), in opening the discussion, remarked that the President had truly described the Report, which was the tenth of the series, as one that would bear comparison with any of its predecessors. That was no small praise, because the series of Reports was remarkable for the range and character of the results which had been obtained and given to the world. It was a matter for congratulation to the Institution that it should have been able to give direction and assistance to scientific workers who had conducted the researches over a very long period of years. It was something like thirteen or fourteen years since he was asked by the late Professor Roberts-Austen to succeed Sir William Anderson as Chairman of the Committee; consequently he spoke from very intimate personal knowledge — although he claimed no personal credit—of what the work had involved to the workers, and what was the value of the results, not merely to

(Sir William H. White, K.C.B.)

British engineers, not merely to engineers throughout the world, but to those engaged in the practical work of metallurgy, and in later years particularly in regard to the improvement of non-ferrous metals and their alloys. He was glad to think that members would have the opportunity of hearing from Sir Gerard Muntz, who represented a name honoured in the manufacture of various non-ferrous alloys and whose great Works had been long and eminently connected with the manufacture of metals, an appreciation of the value of the researches which had been carried out and their influence on the practical work of the world. Speaking as a representative of the users of metals, he ventured to think that not merely had great benefits already been gained, but they were only on the threshold of still greater discoveries, from which those who came after them in the future would benefit. It was a most suggestive fact that, out of Reports made at the instigation of the Institution and published in its Proceedings, there had come already remarkable advances in practical metallurgy, some of which had been made in this country and others had been made abroad. It was no small credit to the Institution to have had such foresight long ago and to have foreseen possibilities which were included in that experimental enquiry which had been adopted and continued without interruption.

The photographs of microstructure which had been thrown upon the screen earlier in the evening recalled to his memory times when in that room he had heard gentlemen—eminent steel manufacturers—refer to microscopic details, now generally accepted as meaning so much when applied to the full scale of manufacture, in terms which indicated their distrust of that mode of investigation. He was not in the least blaming those men; many of them had been pioneers in steel manufacture, but the whole of their training and their life work had been of such a character that it was not easy for them to think that such microscopical details as had been shown upon the screen by means of high magnification—in other words that minute differences in structure, in crystalline formation and in other features—could possibly have the influence and meaning which engineers now felt bound to attach to them. That fact indicated a large and remarkable change of professional opinion amongst both practical metallurgists and engineers.

A casual remark had been made by Dr. Rosenhain in the course of his exposition, in relation to the importance attaching to the use of pure zinc in the research work described. Dr. Rosenhain stated that if the zinc of commerce had been used, it might possibly have produced other results than those he had obtained. This statement illustrated a general principle which all engineers and metallurgists who reflected on the nature of their work must accept, namely, that the highest and best results depended upon minute differences which might well escape ordinary observers. Not a few of the mysterious failures and difficulties of the past had undoubtedly been due to circumstances which were now perfectly intelligible; and in the past they had seemed to be mysterious chiefly, if not entirely, because of a lack of appreciation of the wonderful effect which might be produced by small variations of temperature, by small variations in physical conditions, or in chemical constitutions, or in the nature of impurities which in actual manufacture would probably have been overlooked or neglected. In all branches of engineering and in all branches of metallurgy, investigators at the present time were face to face with the necessity for exercising a skill, a nicety of observation, and a delicacy of constitution which their predecessors naturally thought unnecessary. Engineers now lived in an age when they must work in a manner which those who went before them not merely could not appreciate, but, if he might say so, did not need to appreciate because they were dealing with simple and more elementary problems.

Another thing which all present must have felt as they listened to Dr. Rosenhain had been well expressed by the President. Dr. Rosenhain was a past master in the art of clear exposition, and in him the Institution possessed a research-worker of the highest scientific training, whose reputation as an experimentalist was certainly not surpassed by many, and who, in giving such a wonderful study of another research added to an already long list, had throughout his description and investigation nevertheless looked at results from the practical man's point of view. It was noteworthy

(Sir William H. White, K.C.B.)

that Dr. Rosenhain, in his remarks that evening, had never failed to value and properly appreciate the point of view of the engineer or the metallurgist engaged in actual work. When one thought of what was the attitude assumed by many men of science towards actual workers a generation ago, there had undoubtedly been a wonderful change. On the one side there now existed, as he hoped and believed, a better appreciation on the part of practical men of the value of investigations made by men of science and their possible influence upon the work of engineers and metallurgists; on the other side—and this was equally important—there was a full appreciation by scientific research workers of the actual necessities and conditions attaching to the work of practical men. The two classes had drawn closely together and understood each other better. The time when the pure scientist was accustomed to neglect or depreciate the work of the practical man was past; men of science and men of action now collaborated in a way which was absolutely necessary for securing the best results, and which must promote the welfare of all the professions affected by scientific research. He did not know whether he would carry all the members with him in what he had said, but looking back on his experience as an engineer he welcomed the changes to which he had alluded. He could not say how thankful he was to have lived to see the better condition of things now existing, and it must prove most influential on future developments. They were accustomed to be told that they had to go abroad—particularly across the North Sea—to get the best results, that they lagged behind, that Great Britain did not any longer initiate, and that they were wanting in power of scientific investigation. He thought they might be content to remember when these allegations were made that out of the Reports presented to the Institution in the past had come some of the most remarkable advances made in practical metallurgy, made both in Germany and in France; that the leading authorities of those countries whose opinion was best worth taking had been amongst those who had most fully acknowledged the source of their inspiration and the chief originating cause of progress. It was not necessary to blow their trumpet too loudly; there were no walls of Jericho to fall;

but he despised the man who found his chief enjoyment in depreciating the work or the qualities of the nation to which he belonged.

Sir Gerard A. Muntz, Bart., wished to be allowed to offer his personal congratulations and thanks to the authors for the very instructive and interesting Report that Dr. Rosenhain had placed before them; and he desired to join in the discussion merely as an ordinary manufacturer. The subject of aluminium was one which had considerable interest to him because he had been studying and experimenting with it for some years past, and it was a metal with regard to which up to the present very little had been known. Thanks to the Reports of the Alloys Research Committee, considerably more had been learned in the course of the last year or two upon the subject than was previously the case. Nevertheless, manufacturers were still very much on the fringe of the subject, and were always meeting with something strange which they had not previously experienced. Probably all present had had experience with the alloy "Duralumin," which had been very much to the front in connection with aluminium. He had some knowledge of it, and some of his friends were very intimately concerned in its manufacture. Manufacturers there at once encountered somewhat of a mystery. If duralumin were rolled, when it was hot it was ductile; if it were allowed to lie on the ground for a few moments until it became cool, it was no longer ductile, but became quite hard and nothing could be done with it. It was no longer plastic and soft; the longer it was allowed to lie the harder it became. That behaviour of the alloy puzzled manufacturers very much, and it was only by means of assistance from such scientific workers as the authors that ordinary men could arrive at the reason for these things, because manufacturers had not time to go thoroughly into the matter in the way that scientists could. The phenomenon to which he referred was generally attributed to the presence of magnesium in the alloy; but he had previously cast alloys containing aluminium, not for rolling sheets, but more especially for motor-car castings, and had experienced no trouble with regard

(Sir Gerard A. Muntz, Bart.)

to hardness, so that the effect to which he had referred was evidently not altogether the result of added magnesium, although probably it had something to do with it.

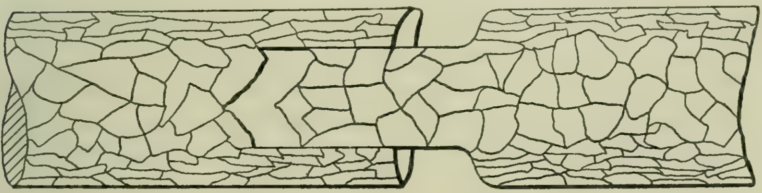
One point that struck him as being of very great interest in connection with the present Report was the percentage of zinc. Personally, his experience practically stopped at a 20 per cent. addition of zinc, because, if a higher percentage than that were added, greater specific gravity was obtained than any of the customers would use. Users seemed to be wedded to the idea that the article they wanted first and last must possess lightness, and that they must get as near as possible to the theoretical specific gravity of pure aluminium. He was very pleased that the authors' investigations had revealed the fact that the mere fact of lightness was by no means everything, and that with the 26 per cent. alloy probably the highest result of all was obtained. The 20 per cent. alloy was the one he had recommended in the past, but, as he had said, it was practically rejected because of the specific gravity. So that although probably better results weight for weight, or rather money for money, putting it in commercial language, would be obtained in a casting with a 20 per cent. alloy than would be obtained with a much lighter alloy more commonly used containing only 10 per cent. of zinc, the users were not content to take it, because they had not got what they thought was the latest thing. Probably the user paid more in the end, because he had to use a heavier section.

Another curious thing that struck him at once in looking through the Report was, that in the matter of rolling rods the research had revealed the very curious fact displayed in Figs. 64 and 68, Plate 18. The authors there dealt with two rods which had been rolled down, the one being $\frac{7}{8}$-inch bar and the other $1\frac{1}{4}$-inch bar. He had not had the opportunity of discussing the matter with Dr. Rosenhain, and he did not know whether that gentleman had, in the course of his experience, met with any manufacturers who had rolled down aluminium rods hot, but until he read the Report he was quite at a loss to understand what happened during that process. In Fig. 64, Plate 18, relating to the

$\frac{7}{8}$-inch hot-rolled bar, the authors showed a close grain metal; and in Fig. 68, which was the $1\frac{1}{4}$-inch hot-rolled bar, they showed a metal with a crystalline formation. In rolling down a large rod, the manufacturer started with a larger billet; he began with about a 4-inch billet, and by the time that billet was rolled down to 2 inches in diameter the curious result was sometimes obtained that the two outer surfaces were somewhat similar to the $\frac{7}{8}$-inch section, whereas the bulk of the metal was similar to the $1\frac{1}{4}$-inch section. He had known the rods break in two in the rolling, a fracture like that shown in Fig. 108 being obtained composed of sections of the close grain metal as shown in the diagram. In the centre an elongated piece was obtained which was absolutely pulled out composed of the larger grain metal. He was puzzled as to why the metal took that form, as it was absolutely in two different sections, there apparently being a tube of metal round a core of soft metal in the middle; it only occurred in certain processes and in certain sizes of metals, and it did not happen in every case, but only now and again. After hearing Dr. Rosenhain's explanation, however, he was able to appreciate what happened, and therefore the Report was very useful to him as a manufacturer from that practical point of view.

Fig. 108.—*Fracture of a Rod broken in two in rolling.*

Outer layer composed of crystals elongated and flattened out by rolling process, inner core consisting of coarse grained crystals.



Another point to which Dr. Rosenhain had referred was the question of the use of pure zinc. He himself had used the alloys for casting purposes and also for rolling, for making rods and tubes both in pure aluminium and the various grades of aluminium zincs.

(Sir Gerard A. Muntz, Bart.)

For ordinary practical purposes it was quite feasible to use a good quality zinc, and not to have to go to such qualities as Brunner-Mond zinc. It was not necessary to go to that expense in manufacturing ordinary commercial articles, that is, ordinary rods or tubes. For such work as was required by Sir Frederick Donaldson, and also for tube work and for motor-car castings, it was quite possible to use a good ordinary Silesian spelter. Those were better in quality than the generally accepted good ordinary brands, and they were good enough for that class of alloy.

He did not desire to express any opinion with regard to corrosion of aluminium, because it was a subject on which he had not experimented. That was a subject which should be investigated by the Alloys Research Committee or possibly the Corrosion Committee of the Institute of Metals, and it would be time to refer to that later on when they reported on some of the questions they already had in hand. It was rather a curious fact, in his experience of alloys, that the use of pure zinc should give better results. He did not at all doubt what the authors said, but in his experience with other alloys he found that as a rule, if pure metal were used, there was more likelihood of galvanic action being obtained than with the commoner metal. Those were matters that were somewhat new. He could only thank the Alloys Research Committee for having completed the particular research referred to, and Dr. Rosenhain for his excellent exposition of it. He also desired to express his regret that such information was not available when he entered business thirty years ago, because it would have saved him considerable work. Instead of having to work, as they had to in those days, with such knowledge as could be picked up in the Science Schools of the day; instead of spending a great deal of money in useless ways, they would have been in the position to go ahead and make money, whereas very often they lost it.

Professor A. K. HUNTINGTON (King's College, London) said the Report abounded in points for discussion, but it was a serious matter to undertake the discussion at a meeting of that kind, and he did not think it would be of any very great advantage to do so in detail.

There was, however, one point which struck him specially to which he would like to refer. Although it did not bear perhaps very directly on the Report, it did bear on all researches of the kind. He referred to the question of making sand-castings for test-pieces. He had been for the last thirty years or more engaged in researches connected with alloys, and for many of those years he used to make sand-castings for test-pieces. A great many were satisfactory, but a great many were not; they caused one much loss of time and a great deal of expense. It was a wearying thing to prepare a metal, which in itself took a considerable time; to make a casting; machine it up; and then when about halfway through with the test to find there was some defect due either to small particles of dross or to gas or what not. In a test-piece a very minute particle, or a very minute cavity on the surface, was very serious indeed so far as the accuracy of the test was concerned; it would inevitably spoil both the breaking load and the elongation, and the test was worth nothing at all from a practical point of view. The result of his experience was that the only way to get comparable results was to cast the metal, or alloy, in an iron chill-mould with a sand head, preferably placed in the centre of the test-piece, at the part at which the bar was ultimately expected to break. He had found that a bar about 6 inches long and with 2 inches of length on which to measure for the elongation was ample for all practical purposes, and was the most economical and in every way the most satisfactory length to work with. At one time it was customary to use 8-inch lengths, and some had advocated that 10-inch lengths should be used owing to the convenience of the decimal system; but it involved much greater difficulty in casting and machining, and there was no real advantage in it—in fact rather the other way.

He desired to impress upon the members for a moment what was really required in making the castings for test purposes. The investigator desired to compare the metal in its cast condition with metal which had had work put upon it, and there was no advantage whatever in the metal being cast in loam or sand.

(Professor A. K. Huntington.)

What the engineer required to do for comparative purposes was to get the cast metal in its best possible condition, and that could never be done by casting in sand. It was true there were certain things to be learned by casting the metal in sand, but it was no use trying to arrive at other properties of the metal and complicating the matter by casting it in sand simply to show how it behaved in sand. He was dwelling on the point perhaps rather fully, but up to the present he might say almost exclusively that work of that kind had been done with pieces cast in sand, and he would be very glad indeed to see that method abolished, because it certainly caused a great waste of time and a great deal of trouble.

Dr. Rosenhain, interposing, said the authors had made both sand- and chill- castings.

Professor Huntington said he quite understood that, but the point he was emphasizing was that it was necessary to get the metal in the best condition and to anneal it in order to obtain comparable results. If it was cast in sand, a certain amount of chill would inevitably be obtained on it. Chill was obtained on the metal no matter how one tried to avoid it, unless there was a big mass of metal and it was allowed to cool exceedingly slowly. So that it was necessary to resort ultimately, if comparable results were required, to annealing, both in the case of the metal cast in sand and in the case of the metal cast in chill. It was necessary really to anneal at different temperatures and also to work at different temperatures in the working of the metal, and to test at different temperatures.

Mr. W. Murray Morrison (British Aluminium Co.) said it had been to his company and to himself a very great pleasure indeed to assist in obtaining the results which the authors had laid before the Institution. Sir William White had struck a very true note when he said that the men of science and the men of practice were drawing much closer together than they had ever been before. It had been his privilege, as a comparatively young man, to work as a manufacturer and an engineer alongside scientific men of high technical skill, and he had gained very much advantage from doing so. The results embodied in the Report would, he knew, when he had time to study them in greater detail, together with the information he had gained from the carrying out of the tests at his company's works, be of very great advantage in the practical application of the art.

Mr. Henry Fowler suggested that in future, before the Reports of the Alloys Research Committee were published, details of any particular alloys the Reporter thought might be of practical use and which would be referred to in the Report should be sent to the large users in the country. If that were done, engineers would have an opportunity of testing the various alloys and relating their experiences of them at the Meetings of the Institution. He thought that would be of great assistance to those who hoped to make use of such alloys later. He hardly agreed with the remarks Professor Huntington had made on the question of making sand-castings for test-pieces, because he thought cast test-pieces must of necessity be of the very greatest assistance to those who had to use the metal in that state later on.

Sir William H. White, K.C.B. (Past-President), said there were several questions in regard to corrosion which he had not alluded to in his opening speech but which he would now like to ask, as he could not be present at the adjourned discussion. The authors very justly said that in corrosion local pitting, especially in alloys where zinc was present, was often a matter of great practical importance. That was quite true, as all engineers knew who had to do with under-water fittings in ships. What he wished to know was whether in the experiments on corrosion, so far as they had been carried out, there had been any indication of severe local pitting. Questions relating to the best way of testing, whether by loss per unit of surface or by the method stress on reduced specimens, were matters of great scientific interest, but the question of practical

(Sir William H. White, K.C.B.)

importance was whether alloys had been obtained which would wear fairly uniformly or whether there was any marked tendency to local pitting. It would be interesting if the author could produce specimens that showed that state of things. He was not speaking at the present time of what had happened to the parts near the attachments of the test-plates; that was quite a different thing. It was necessary to remember too that the experiments made under the wharf at Portsmouth were a continuation of a long series of experiments which had been made there on various alloys in connection with the use of copper sheathing and matters of that nature. Consequently a good comparison could be made between different specimens tested at various times. But even then the conditions of test did not and could not cover all the conditions of actual practice, and although they were very valuable for purposes of comparison, they were only so to be regarded. The Admiralty had been generous in the matter and with good reason, because as the nation paid for the ships of the Navy any economies that could be effected as a result of the Institution's researches would come back to the nation and to them individually as taxpayers, which at present was a matter of some importance. He would also be glad to know whether there had been any indication of galvanic action being set up between the constituent parts of the alloys in connection with any of the experiments made.

He desired to add one further remark in conclusion, namely, that while the Institution was most grateful to the gentlemen and the firms who had aided the National Physical Laboratory with materials for recent experiments and by the use of their premises, it must not be forgotten that from the very start of the aluminium research the Institution had been helped in the most generous way all round. From the very first, when Dr. Carpenter was occupying the position of Reporter, the British Aluminium Company had helped the Institution; the Broughton Copper Company had also helped nobly; the Thermit Company helped them with manganese; and Messrs. Brunner, Mond and Co. now helped with zinc. He hoped that, with such examples before them, the Institution might be sure that, in whatever direction they extended their enquiries, they would not have to pay much for the materials used for research.

Mr. **Leonard Archbutt** (Loco. Dept., Midland Railway) said he did not think anyone could read the three Reports in which the results of the investigations had been set out without being impressed with the enormous amount of work which it had involved, and also with the great accuracy and thoroughness with which it had been done. He rose for the purpose of saying a few words with reference to the corrosion experiments. He understood it was the intention not to make any further experiments by measuring the loss of weight, but to replace those by experiments made with test-pieces.

Dr. **Rosenhain** said that that was a misapprehension on Mr. Archbutt's part; the Committee intended to do both.

Mr. **Leonard Archbutt** replied that he was glad to hear that statement, because he was about to suggest that both kinds of experiments should be made. Local pitting might be obtained, which would greatly reduce the strength of a test-piece and yet would not have the same effect as general corrosion in a loss of weight experiment. He was not aware of all the purposes for which the alloys referred to in the Report might be used, but the fact that the corrosion experiments up to the present time were being made in sea-water suggested that the alloys were going to be used in sea-water, and so long as that was the case, that was of course the proper medium in which to test them. But if the alloys were likely to be brought in contact with, say, liquids containing free fatty acids he suggested that further experiments should be made upon the alloys in those media, and the effect of warm water might also be tried. Generally speaking, he thought that experiments on corrosion ought to be made under the conditions in which the corrosion was likely to occur in practice. He had no doubt that all these points had suggested themselves to the authors, but he thought it just as well to mention them, because it very frequently happened

(Mr. Leonard Archbutt.)

that the corrodibility of a metal under one set of conditions was judged by its behaviour under an altogether different set of conditions, which sometimes led to very misleading results.

Sir H. Frederick Donaldson, K.C.B. (Vice-President), said that it was with some hesitation that he intervened in this discussion, because he had not been able to give the Report the close study which it undoubtedly deserved, and moreover the comparisons which he was about to make with certain figures could not be regarded as altogether conclusive, because the bulk of the alloys mentioned contained about 1 per cent. of copper, which might make a great difference on the results. However that might be, the results to which he was about to refer were obtained on more of a manufacturing than a laboratory scale, and had been made with commercial ingredients, not aiming at the special purity which the authors' experiments had covered. This again might have its effect on some of the comparative figures.

Casting temperatures were referred to (page 345), and though we should agree that these should be kept as low as possible to prevent loss by oxidation, the temperature advocated by the authors appeared to be too low for general foundry use. The following gave comparisons of results obtained from an alloy of 19 per cent. zinc, 1 per cent. copper, and 80 per cent. aluminium, in chilled castings:—

Casting Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
° C.	° F.	Tons per sq. in.	Tons per sq. in.	Per cent.
850	1562	6·5	9·1	1·8
800	1472	7·8	13·1	4·0
700	1292	7·5	9·8	2·45
650	1202	6·6	9·1	0·75

The commencement of solidification in these experiments was about 610° C. (1130° F.).

There was considerable similarity to be observed in the case of the alloy cast at 800° C. (1472° F.) with Alloy No. 20 (Al 80 per cent. and zinc 20 per cent.) shown on Table 5 (page 353), which gave:—Yield-point, 7·8 tons per square inch; ultimate stress, 13·82 tons per square inch; elongation on 2 inches, 4·0 per cent.

With regard to rolling temperatures (page 370), here again he must take the alloy with the 1 per cent. copper; and it was found that temperatures of from 500° to 450° C. (932° to 842° F.) gave excellent results. An alloy of 15 per cent. zinc and 85 per cent. aluminium had also been rolled at this temperature with excellent results. This appeared to be contrary to the authors' experience (page 416), where it was stated that at temperatures above 400° C. (752° F.) these alloys were too brittle to withstand the process of rolling into bars. The experience obtained at Woolwich was that alloys containing copper did not roll very well at a temperature of 350° C. (662° F.), but the 15 per cent. zinc and 85 per cent. aluminium did so, but not with the same ease as at 500° to 450° C. The reduction made in these rolls was about $\frac{1}{8}$ inch per pass.

He would like to quote the results of aluminium alloy with an approximate composition of zinc 15 per cent. and aluminium 85 per cent., where the following results were secured:—

No.	Treatment.	Yield-Point.	Tensile Stress.	Elongation on 2 in.
		Tons per sq. in.	Tons per sq. in.	Per cent.
1	Sand casting	5·7	9·5	4·5
2	Chill casting	3·5	8·2	6·5
3	Hot rolled 450–500° C. from 3 in. to $1\frac{3}{4}$ in.	4·2	12·7	2·8
4	Bar 3 subsequently rolled cold to $1\frac{5}{8}$ in.	11·2	14·6	14·5
5	Hot rolled 350° from 3 in. to $1\frac{3}{4}$ in.	6·5	13·5	20·5
6	Bar 5 subsequently rolled cold to $1\frac{5}{8}$ in.	11·2	14·3	15·5

Mixing:—Zinc 7·5 lb.; Aluminium 42·5 lb.

Tests 1 to 6 were all from one melt. The bar rolled well at 450–500° C. Some small surface cracks occurred in the bar rolled at 350° C.

(Sir H. Frederick Donaldson, K.C.B.)

The experience of the authors that cold rolling decreased the tensile strength (page 390) was supported in the Woolwich Arsenal work, where applied to the ternary alloy of 18 per cent. zinc and 1 per cent. copper, hot rolled from 3 inches to 1⅝ inch :—

—	Yield-Point.	Ultimate Stress.	Elongation on 2 in.
	Tons per sq. in.	Tons per sq. in.	Per cent.
Hot rolled from 3 in. to 1⅝ in. . .	8·0	20	21·5
Part of the same bar, but with the last ⅛ in. reduction cold rolled .	11·5	18·3	17

It was interesting to note that the effect of cold rolling on the alloy containing 10 per cent. zinc and 1 per cent. copper was about the same as for the 18 per cent. zinc and 1 per cent. copper.

A billet was rolled hot from 3 inches to 1⅞ inch, then further rolled, part of it cold, to 1¾ inch, and a part of this last bar further rolled cold to 1⅝ inch diameter. It would be seen from the following tests that there was no decrease on the ultimate stress in this case :—

Treatment.	Yield-Point.	Ultimate Stress.	Elongation on 2 in.
	Tons per sq. in.	Tons per sq. in.	Per cent.
Rolled hot from 3 in. to 1⅞ in. .	4·9	10·6	25
Part of above bar rolled cold from 1⅞ in. to 1¾ in.	10·2	13·0	15·5
Part of above bar further rolled cold from 1¾ in. to 1⅝ in. . . .	12·5	14·0	7·5

There seemed to be some contradiction on two points in the Report, but which doubtless the authors would be able to clear up. It was stated on page 327 that this somewhat abnormal behaviour (presumably at temperatures above 400° C.) made it possible to roll into bars alloys which were brittle in the cast state, while on page 416 it was stated that the authors' experience at the rolling-mills indicated clearly that above 400° these materials were too brittle to withstand the process of rolling into bars.

The following results of tests might be useful as comparisons :—

Experiment, Alloy No. 15.	Yield-Point.	Ultimate Stress.	Elongation on 2 in.
	Tons per sq. in.	Tons per sq. in.	Per cent.
Sand-casting	9·6	11·14	2·0
Chill-casting	5·8	11·69	8·5
The experiments showed with Zn 15%, Al 85% :—			
Sand-casting	5·7	9·5	4·5
Chill-casting	3·5	8·2	6·5
And comparing this with the alloy containing 1% of copper, viz. Zn 15%, Cu 1%, Al 84%, where the results were :—			
Sand-casting	4·8	8·6	4·5
Chill-casting	4·0	8·8	4·5

In conclusion he would like to say that his remarks were not advanced as in any way a criticism on any part of the Report, so much as a desire to add some data from experience on a manufacturing scale which might assist the authors and others in investigating the subject.

Discussion on Friday, 3rd May 1912.

The PRESIDENT stated that Mr. Archbutt desired to lay some additional information before the members, and he would therefore call upon him to open the resumed discussion.

Mr. S. L. ARCHBUTT, in opening the resumed discussion, said that although the authors had endeavoured to make the Report as complete as possible, certain additional data appeared desirable in connection with the points raised in the discussion and in conversation since its presentation. The first question to which he wished to refer was the effect of using ordinary foundry spelter instead of specially pure zinc; this had already been mentioned in connection with the corrosion tests. They had since made some tensile tests on chill-castings containing zinc obtained from a local brass-founder—he thought Professor Huntington would be pleased to hear that in this case they had not made any sand-castings—alloys containing 10, 15, 20, and 25 per cent. of zinc in quantities of about 5 lb. each had been made, the usual small chill billets being cast. As would be seen from the Table of results (page 463) the castings made from pure zinc, apart from the somewhat lower yield-points of alloys Nos. 15, 20, and 26 and the slightly lower elongation of No. 20, were decidedly superior. The ultimate stresses were on the average 2 tons higher; in the case of alloy No. 26 the difference was as much as 3 tons. The superior elongation of the alloys containing pure zinc was very evident for low zinc-content.

Dr. Rosenhain in his reply to Sir Frederick Donaldson would give some further figures, the interpretation of which seemed to rest largely on the deleterious influence of impure zinc. It should be pointed out that the superior figures given by the pure zinc alloys were no doubt in part due to their having been made in larger quantities.

*Tensile Tests on Chill Castings made with specially pure Zinc (underlined) and with Foundry Spelter.**

No. of Alloy.		Yield-Point.		Ultimate Stress.		Elongation on 2 inches.	
		Tons per sq. in.	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
10	$\underline{11}$	4·41	$\underline{5·0}$	7·85	$\underline{10·24}$	9	$\underline{16}$
15		6·59	$\underline{5·8}$	10·64	$\underline{11·69}$	6	$\underline{8·5}$
20		8·22	$\underline{7·8}$	11·12	$\underline{13·82}$	5	$\underline{4}$
25	$\underline{26}$	12·04	$\underline{10·6}$	14·64	$\underline{17·7}$	2·5	$\underline{4}$

The next point to which he wished to call attention was the thermal expansion of the alloys. It had been suggested that the alloys might be used in large structures where their thermal expansion would be important. Through the kindness of Messrs. Sears and Donaldson, of the Metrology Department of the National Physical Laboratory, determinations had been made of the coefficient of thermal expansion of alloys containing 5 and 15 per cent. of zinc in the form of $\frac{13}{16}$-inch bars drawn with annealing and one metre long. These had been compared with the Laboratory Standards between the temperatures 0° and 18° C. The values of the coefficients were 0·0000227 and 0·0000231 respectively. Unfortunately only one alloy was available in the form of $\frac{7}{8}$-inch hot-rolled bar, namely, No. 20, and this gave a value of 0·0000234. One of the ternary alloys containing 3 per cent. of copper in the form of $\frac{1}{2}$-inch rolled bar gave a value of 0·0000234 also.

Mr. L. Pendred enquired whether Mr. Archbutt could state how those figures compared with steel.

Mr. Archbutt replied that they were of the order of twice that of steel. For casting purposes the authors had been asked to

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* On analysis this was found to contain 1·99 per cent. of lead.

(Mr. S. L. Archbutt.)

determine the total contraction, that is, how much smaller the casting was than the pattern. To do that they cast a rectangular bar 13 inches long by $\frac{3}{4}$ inch square from a pattern with two small projecting points near the ends. In one case the authors used the points on the pattern, and in the second case they removed the pattern and made two indentations in the sand with the points of a beam compass at a measured distance apart. The casting was removed from the sand as soon as it was sufficiently hard. The distance between the points was measured on the pattern and then on the casting when quite cold. Alloys containing 20 per cent. of zinc, and 25 per cent. of zinc and 3 per cent. of copper, were tried, and the contraction in both cases was found to be rather over 1 per cent. The 25/3 alloy gave the higher result, namely 1·1, but the order of the results was about 1 per cent. He understood that those figures were what would be expected for aluminium alloys; their pattern maker informed him that with the aluminium alloy he would work on what he called a $\frac{1}{96}$ scale, that is, he allowed $\frac{1}{96}$-inch contraction on 1 inch, which was equivalent to about 1·04 per cent. In the case of brass and gun-metal it worked out at about 1·06 per cent. and for cast-iron he allowed $\frac{1}{120}$, which was 0·833 per cent., the amount of contraction allowed for always being dependent more or less on the nature of the casting.

Professor J. O. Arnold (University of Sheffield) said that the subject of alloys of aluminium and zinc was one of very great interest at the present moment in connection with aviation, and it was one which in his opinion required approaching with great caution. Looking at aviation generally, he would say that the possibilities seemed at present limited to two branches of utility, that of sport and that of military tactics, in both of which danger was no object. He desired very much to congratulate the authors upon the colossal piece of work which they had turned out with such very great ability.

The Report was admirably arranged clerically, and he ventured to suggest in connection with such papers that that was an innovation. The research had been made on a basis which the

University of Sheffield had introduced about twenty years ago, namely, on the basis of correlation. The authors had correlated in a most skilful manner the chemical and micrographical analyses: the recalescence curves and the mechanical tests, static and kinetic. The tendency amongst the physical chemists in other universities, whose work they all welcomed, was rather to ignore the mechanical tests, whether kinetic or static, and in his opinion that was rather like playing "Hamlet" and leaving out the Prince of Denmark so far as metallurgists and mechanical engineers were concerned. Metallurgists were very glad to have had all the physical and chemical data which could be given, but they wished to know the ultimate result of it from an engineering and a metallurgical point of view, because that was, in his opinion, the final Court of Appeal.

He noticed in Table 42 (page 411) some very interesting results, which were worthy of considerable thought, on the influence of temperature on mechanical tests. It appeared that at 100° C. the ultimate stress of one of the alloys was 14 tons, and the elongation 18 per cent. At a temperature of 595° C. the ultimate stress was 0·35 of a ton and the elongation 130 per cent. He inferred that those figures referred to similar alloys to those shown by the author which had been drawn out to a point. That was a subject which required very careful consideration. An elongation of 130 per cent. was very remarkable, but the strength was absolutely gone. That result seemed to him somewhat on the lines of a report which was published in the University of Sheffield a very long time ago with reference to the influence of bismuth on gold. It had been a well ascertained fact that if even 0·1 per cent. or $\frac{1}{1,000}$ part of the element bismuth was added to pure gold the mass became absolutely brittle. Certain theories were put forward to account for so remarkable a phenomenon, and some experiments were made in Sheffield in which it was shown micrographically (that being the first time that micrographical analysis was applied to gold) that a eutectic alloy of gold and bismuth formed, and a true crystallization was thrown off in a crystal state to the edge of the pure gold crystals, so that there

(Professor J. O. Arnold.)

was, as it were, a solid stone wall of good gold bound together by rotten mortar. The most remarkable result was that at quite a low temperature, black heat, the alloy softened so that the cells of gold could be powdered free from the cement, and then they beat out perfectly into gold leaf. The majority of the mass was quite ductile, but it was entirely spoiled by the brittle cement. He did not know whether the authors could give any explanation as to how that enormous lowering of tenacity came about. It would be very interesting if they could suggest whether it had any analogy whatever to the phenomenon he had just mentioned.

Turning to the elastic limit curves on Fig. 95 (page 417), he again wished to congratulate the National Physical Laboratory on the extreme accuracy of those curves. He thought he was right in saying that they were taken by the authors on Professor Ewing's extensometer. If those curves were carefully studied, it would be noticed that the proportional line in the curve was very remarkable. Hardly a single point observed fell off the proportional line, and when what he ventured to call Range B of the stress-strain diagram was inspected it would be seen that it was quite a good curve clean off the proportional line. Those curves were of considerable importance. He did not know whether he was asking for too much, but he would like to ask whether the authors had any data which might correlate, from the elastic limit which had been obtained, the Wöhler phenomenon of those curves, and whether they bore any resemblance to steel.

Turning to Table 55 (page 435) in connection with the alternating-stress tests, which he was extremely glad to make at Sheffield for the authors, as the authors had remarked the results from their point of view showed that the alloys in alternation—he meant an alternation such as a double connecting-rod would endure—varied from about $\frac{1}{8}$ to $\frac{1}{4}$ that of a properly treated mild-steel such as was generally used for the purpose. He did not want to labour the point, but he did feel a certain responsibility in asking the members to consider the matter very carefully. He noticed that the authors had put some further figures on the wall, but he presumed that they applied to static tests only.

Dr. ROSENHAIN replied in the affirmative.

Professor ARNOLD thought that static tests for work to which those alloys would be put was a matter of relatively small importance. Remembering the machines into which those pieces would be put, engineers would have mainly to consider very rapid, violent alternating stresses. That was his own opinion, and he would like to hear the authors' view on that very vital matter. He took it that the best alloy had a specific gravity of about 3·2, considerably less than half that of steel. Engineers wanted to know in regard to such alloys what was the proper area to replace steel, whether in static or in kinetic stresses, before they could come to any conclusion as to the reliability of those alloys in connection with aviation.

In conclusion, he again desired to make an appeal to those gentlemen who were carrying out the physical chemistry courses in the Universities, more particularly with reference to metals. He had already stated that he highly valued their work, but he did think they should take within their purview the opinions of those who were practically making the metals, and who, if he might say so, understood things about them which the scientific gentlemen did not. More particularly in connection with equilibrium curves and various other points he appealed to them not to stand too much upon their own results, but to try and work with practical metallurgists. If that state of affairs was brought about, he thought the combined labours of both would be not only of great value to metallurgists themselves, but even of more value to mechanical engineers.

Mr. WILLIAM MILLS said that he personally was one of the earliest practical workers in the metals under discussion, and he wished that practical workers had had such an intensely interesting Report put before them ten or fifteen years ago; it would have saved a great deal of labour, worry, and tests. He himself had carried out quite a little research in a rough and ready manner into the subject, comprising a great number of tests. He had had the

Mr. William Mills.)

assistance in that work of Professor R. M. Ferrier, who was now at the University of Bristol. He (Mr. Mills) made the alloys according to his own ideas, and Professor Ferrier made the tests. At first it was very difficult to know what to do; he had no data or Papers such as the present one to go upon, and he had therefore to work in the dark. He began first with binary alloys—copper and aluminium—and soon found that very little could be obtained from them. Aluminium and zinc were then tried; and although he did not obtain such results as the authors, many interesting results were achieved. Difficulties, however, were soon experienced in casting the metal. The castings exhibited by the authors were of an exceptionally simple kind, but such castings as motor-car crank and gear cases, especially some varieties, were very difficult indeed to cast, so difficult that he had heard large steel founders say they would not attempt to cast them. They had to put up with stresses that were pulling the one against the other, and the castings were inclined to crack in all directions, unless special means were used for obtaining sound castings.

Since he received the Report he had unfortunately not been able to make the tests he would have liked to do with the aluminium-zinc alloys, but in the near future he intended to make a few tests, and he hoped then he would know whether it would be possible to cast intricate castings in aluminium-zinc the same as could be cast at present in aluminium, zinc, and copper. The Report had revealed to him possibilities that he had no idea could be obtained with aluminium-zinc alloys. Unfortunately he had not with him the records of the tests to which he referred that were made between ten and sixteen years ago, but he remembered that they came very near the special alloy that the authors in their Appendix (page 441) stated had given the best results. They used within 2 to 3 per cent. of aluminium, within 2 per cent. of copper and within 3 per cent. of zinc that the authors had used, and frequently obtained a stress of 20 tons per square inch and over. At the time they thought they had obtained something very good. They then made, and still continued to make, a large number of castings in that alloy, but unfortunately, as Sir Gerard Muntz had said at the last Meeting, a lighter alloy was now demanded. Customers wanted an alloy as near as possible to the specific gravity of pure aluminium. He had argued the question with them, but various firms had specifications and wished the manufacturers to work to them. He considered that the alloy they wanted (specific gravity of 2·86) was not nearly rigid enough; personally, he thought an alloy very nearly approaching the alloy mentioned in the Appendix was really the best known so far. He wished he could have continued the research he began, because had he not obtained an alloy better than had so far been achieved, he would have been very disappointed. He thought there were very great possibilities in the metal, much greater than had ever been obtained in the past.

Although the research dealt with in the Report was a very extensive one, he did not think that more than the fringe of the subject had as yet been touched, and thought it possible very much higher results would eventually be obtained. The authors were to be congratulated on their work, and the Institution was to be congratulated on having an Alloys Research Committee. He hoped the work would be continued, and he looked forward to the results from the ternary alloys with much more interest than the results from the binary alloys. He quite agreed with the authors that aluminium-zinc alloys were credited with undesirable properties, and not without reason. While in Paris during the previous January he had a long conversation with an expert who showed him two or three castings made in aluminium-zinc which were warped and cracked all over. The gentleman to whom he was speaking told him that when the castings were made they were perfect, and that simply the influence of time had turned them into their present condition. Dr. Rosenhain had stated that he thought those difficulties would be overcome by the use of pure zinc. He (Mr. Mills) hoped that would be the case, and saw no reason why it should not be. He intended to make some rather difficult castings and hand them over to the authors for investigation, although it would take some years to make the tests.

With regard to the question of contraction to which Mr. Archbutt had referred at the opening of the Meeting, it would, he thought,

(Mr. William Mills.)

be of interest if he stated that he found 1 in 72 was the best contraction rule for the difference between the pattern and the casting. The mechanical properties of the zinc alloys were a surprise to him. In connection with Professor Arnold's remarks as to the effect of heat and how the castings would stand it, he would like to give a simple illustration. In the crank-case of a motor-car the heat passed from the cylinder to the crank-case; and that was a very good practical illustration of its ability to stand stresses under a certain amount of heat.

The results of the corrosion tests were most interesting. He had not looked forward to such good results as those the authors had obtained from specimens totally immersed in sea-water, but he would like to see a comparison of results between sea-water and air and also on the deck of a ship. In the fittings inside cabins, such as hat and coat pegs and similar articles, the alloys stood well. About fifteen years ago his firm supplied a complete set for a cabin, and he had not yet heard that they had been dispensed with. He had had a large number of specimens of different alloys hung out within a half a mile of the sea and within 200 or 300 yards of a river, but not in the water; the last time he saw them there was practically no difference, and very little corrosion existed, although he expected to see them practically corroded away. No special means were taken to protect them; they were simply screwed to a board which was screwed to the wall of a building, and exposed to all weathers. The data connected with them had unfortunately been lost.

With regard to the question of ageing, he had noticed that in one specimen (page 352) the result obtained was about 2 tons higher after an alloy had been kept for sixteen months. It was not surprising that the tests were higher, but it was surprising to find they were so much higher. An interesting feature in certain of the lighter alloys was that if an attempt were made to machine them directly they were cast, the metal "dragged" and was very difficult to machine; but after keeping it for a few weeks, and especially a few months, the same casting would machine quite easily—quite as well as soft machine-brass. He noticed there was a difference between chill- and sand-castings. Chill-castings seemed to decrease in strength in many cases, shown in Table 34 (page 406), while the sand-castings increased in strength. That result was rather surprising, but perhaps with more experience it would be remedied. The secret of obtaining proper chill-castings was to get to know the right temperature of the chills; and the want of uniformity might be remedied if the authors were to look more into the question of the heating of the chills.

He would like to congratulate the authors on the invention of the term "specific tenacity." Workers in aluminium had required some such term ever since he had been in the industry, to compare the results with other metals generally. Such a term had not been required until the introduction of the light alloys; but he could not quite agree with the authors in their formula (page 360), for the following reason. If it should get into the Press that with regard to the No. 26 Alloy, giving about 17 tons per square inch ultimate stress, the specific tenacity of that alloy was 150 tons, or nearly nine times as much as the present figure, manufacturers would soon have enquiries for Dr. Rosenhain's specific tenacity alloy giving 150 tons per square inch, and he was afraid that would lead to a great amount of correspondence. He himself would rather the comparison were made from some well-known material, and he would alter the formula to read as follows :—

$$\text{The Specific Tenacity} = \frac{\text{Ultimate Stress in Tons per square inch}}{\text{Weight of one cubic inch in lb.} \times 3\cdot 6}$$

(The Specific Tenacity is the Breaking Load, in Tons, of a bar whose Weight is 1 lb. per 3·6 inches in length.)

The figures 3·6 represented the length of a bar of wrought-iron of 1-inch section weighing 1 lb. If that were taken as a standard, they would then compare all material to wrought-iron. The specific tenacity of wrought-iron would then be exactly the same as the tensile strength. Engineers knew iron exceptionally well, but if one were asked to state the breaking-strain of a certain wood, say beech, or of an aluminium alloy, he could not answer. It was only a question of calculation. The specific tenacity formula, if it was

(Mr. William Mills.)

any good, was good for comparison. When a manufacturer was speaking to people about aluminium alloys, in a rough and ready way the consumer spoke of material giving 10 or 15 tons per square inch, and asked that that should be guaranteed. His firm had contracted to make something like 500 castings. The test-pieces were cast on, and every casting that did not give 11 tons was thrown out. A very small percentage indeed was thrown out. When discussing the strength of aluminium alloys, and comparing them with copper, they simply multiplied the tensile test by 3·3, or 3·1 for brass, and roughly 2·9 for iron and steel, and that gave a rough and ready comparison. If the alteration he had suggested were adopted, it would not in any way be condemned from a scientific point of view, and would be much more useful for practical engineers.

As a manufacturer he entirely agreed with the methods of the authors in using the purest metal and alloys it was possible to obtain. If they had used any other, the Research would have been useless, as manufacturers wanted to know the very best results that could be obtained by the most careful and scientific methods it was possible to adopt, so that they would have an ideal to work to.

Mr. F. W. HARBORD said that, in connection with the question of making castings, the authors stated they had experienced no difficulty in avoiding the cracking of castings due to the tenderness of the alloys when hot. He thought it was necessary to be careful in making such generalizations, because he assumed that, under the conditions of their work, they were only able to make very small castings; and if they had to make intricate castings on the much larger scale referred to by the last speaker it might be found that the results obtained were very different.

In dealing with the corrosion tests and impurities (page 324), the authors seemed to think that corrosion and disintegration from ageing were largely due to the impurities in the zinc, and that if pure zinc was used those difficulties would be overcome. The impurities of commercial zinc so far as he knew were practically iron and lead, and he would like to ask the authors which of those impurities had led them to the conclusion that they would be likely to cause corrosion in the alloys. For many purposes, impure zinc in alloys gave quite as good results as pure zinc. There was a certain amount of iron present in the aluminium, so that it was not likely to be the small amount of iron that was present in commerical zinc that affected the result, and he would be very doubtful about lead having this effect, unless the authors could adduce some direct evidence to support this.

Some results were given (page 375) of tensile tests. There was one point, to which he had referred before in connection with these researches, to which he wished again to direct attention, namely, that he thought it would be desirable if the authors could always give the two duplicate tests. He knew that would take up a little more room, but only a little more. It was so important to know in tensile tests what the order of the difference was between duplicate tests—the error due to the machine, and the ordinary method of testing, and to variation in the material itself. If only one result was given as the mean of two results, the reader did not know what was the difference due to variation in the material itself. For instance, in mild steel a difference of 1 ton on the same plate was not uncommon. The authors said in one case, in No. 20, that there was a difference of as much as 1·6 tons, and on referring to Table 12 (page 373) he noticed this was as much difference as there was between Nos. 19 and 20, so that it was important to know in considering the figures what the difference was between two duplicate sets.

He noticed that all the preliminary tests were made on 2-inch cast bars. He did not think it mattered very much in the case of cast bars, because the reduction of area was very small; but the preliminary tests on the rolled sections were also made on 2-inch bars with the exception of the ½-inch bars, when the elongation was taken on 1 inch. In the Table it was given as 1 inch, whereas in the sketch of the test-bar it was marked 1·5. He was, therefore, not quite sure whether the elongation was measured on 1·5 inch or 1 inch.

Dr. ROSENHAIN said the elongation was measured on 1 inch in that case.

Mr. HARBORD said that, taking an elongation of 1 inch on material in which there was a reduction in area of something like 46·68, it was impossible to picture exactly what the true elongation was, and he thought it would have saved a good deal of work if the authors had taken the first tests on 8 inches as they ultimately did on a great many of the samples in the latter part of their work. He did not see any point in taking all those tests on 1 inch. The reason given for having the 1-inch bar, and taking the elongation at 1 inch in the case of the ½-inch bar, was that it was the ratio of diameter to gauge length recommended by the Engineering Standards Committee. He thought that must be a mistake, because as far as he knew the Engineering Standards Committee nowhere recommended less than 2 inches gauge length. He was now speaking of mild steel and similar material which had great ductility. When 2 inches could not be obtained, or when it was a very small bar, the Engineering Standards Committee recommended that the gauge length should be eight times the diameter of the bar. In the case under discussion that would have given the authors a gauge length of rather over 2 inches. Personally he thought 2 inches was quite small enough, in fact it was far too small if it could possibly be avoided with material of such ductility.

In Table 47 (page 421) he noticed that in two cases the yield-points were given as the mean of two results. Those results in one case were 10·36 and 14·4, and in the other 11·4 and 20. He did not think it was quite justifiable to take the mean of two results of 11 and 20. In a case of that sort he thought other pieces should have been tried and duplicate results obtained, because there was no more reason for supposing that the mean 15 was right than that 11 or 20 was right. The probability was that those two discordant results were due to some flaw or slight defect in the test-piece. That emphasized the point he had just referred to of the great importance of giving duplicate figures in order to arrive at results.

With reference to the corrosion tests (page 437), he thought it was rather a pity that they were done in sea-water, as these alloys were not likely to be used under such conditions. All of those who had carried out such experimental work were very anxious to get results as soon as possible, and as sea-water would be more active than air, results would be obtained sooner in sea-water than in air, or if the alloy was exposed to spray as it would be on board a steamer. He thought, however, that the corrosion tests as taken were rather misleading. If elaborate precautions were taken to isolate the material from wood, string, and so on, clearly the results obtained from metal which had to be treated in that tender way were not of much good. He thought it would be better in all such cases to try and get a result under more or less reasonable practical conditions. Metallic contact and electrolytic action were prevented possibly by the measures adopted by the authors, but it was necessary to carry out experiments on the materials in the way in which they were intended to be applied in practice—under what might be called practical conditions. He noticed also that the authors compared the results with those obtained with Muntz Metal and he thought with Naval Brass. On page 439 they said, "As regards the actual rate of corrosion as indicated by these figures, the loss of weight per square foot per month is closely comparable with that previously found for such alloys as Naval Brass and Muntz Metal." He was not quite clear from that whether the results which they were comparing were made at a different time and under different conditions, because if so they were of course not comparable. He would like to know if the Muntz Metal and Naval Brass were as carefully isolated and all the same precautionary measures were taken as with these alloys, and if the tests were made at the same time in the same sea-water, because it was well known that very slightly varying conditions appreciably affected the corrosion of those metals.

The Report contained a mass of information, which it was almost impossible to digest in anything like a reasonable time, and the amount of work involved in it could only be fully appreciated by those who had attempted to carry out similar work. The

(Mr. F. W. Harbord.)

authors were to be most heartily congratulated on the large amount of information they had embodied in the Report, and on the systematic way in which they had presented it to the Institution; he was sure all the members felt very grateful to them for the work they had done.

Mr. EDWARD F. LAW said that Mr. Harbord and Mr. Mills had raised so many of the points to which he intended to refer that he had very little to say. The authors had given so much information that he was going to ask them for more. He noticed that the Report was subject to revision, and he therefore asked them if they would amplify their remarks and make one or two additions which he ventured to think would add to its value. In the first place, the authors referred to what they described as two undesirable properties of the alloys (page 324), and then they proceeded to dismiss them in what appeared to him rather a perfunctory way. His own experience was that behind those prejudices—if they were prejudices—there was usually a basis of truth, and he therefore thought the opinions were required of practical men on the question of the cracking of castings. Mr. Mills had given his opinion, and he hoped that other gentlemen who had had practical experience of the alloys would give their opinions too.

He also thought further information was required, as Mr. Harbord had pointed out, on the question of corrosion. The authors merely stated that abnormal corrosion was due to impurities. Personally he thought it was essential to know more about those impurities; it was a matter of vital importance to the manufacturers, and he hoped when the Report was finished the authors would give more information on that point. The necessity which seemed to exist for elaborate precautions for insulating the alloys rather went to show that they were liable to corrosion. In practice it was hardly possible to insulate them in that careful way. He thought there were two things to be borne in mind in connection with the two prejudices against the alloys which the authors admitted were widely held by practical men. In the first place the manufacturers, as Mr. Mills had pointed out, had to make very complex castings, and, in the second place, manufacturers did not have specially pure zinc presented to them by Sir John Brunner.

As regards the question of ageing, the authors said (page 329): "The question of the possible 'ageing' or even gradual spontaneous disintegration of the aluminium-zinc alloys has also been studied in connection with the sand-cast material, tensile tests on some of the alloys being repeated on specimens which had been kept for over fifteen months, but no signs of any change were observed." On looking through the body of the Report he found in Table 4 (page 352) that very distinct changes took place, and he wished to point out that in every case the yield-point and the ultimate stress had risen. It was true that in some cases the rise was very small, but was it a coincidence that in every case it did show a rise? He would like to hear a little more about the question of ageing. He was anxious to see if the authors could reconcile their figures and their conclusions, but the only reference to the subject was to be found on page 354, where they said: "The comparative results are given in Table 4 (page 352), and it will be seen that there is no sign whatever of any diminution of tensile strength, so that if these alloys are subject to any ageing process at all it must be of an extremely gradual character." Why did the authors say, "There is no sign whatever of any diminution of tensile strength"? Why should it be a diminution of tensile strength?

Dr. ROSENHAIN said that if they were falling to pieces they were probably getting weaker.

Mr. LAW said the falling to pieces or, at any rate, the ageing might be preceded by hardening and an increase of the tensile strength, and moreover it had to be borne in mind that they had only been kept for ten or sixteen months, which was not a very long time in the life of a metal. The points which he had raised dealt with the authors' interpretation of their results rather than with the results themselves, and he desired in conclusion to express his congratulations to the authors on their very valuable Report.

Captain H. **Riall Sankey** (Member of Council) said that nine years ago he instituted some experiments at Messrs. Willans and Robinson's Works to obtain the best aluminium-zinc alloys for casting crank-chambers for petrol engines. To the best of his recollection the best alloys contained from 15 per cent. to 20 per cent. of zinc. The tensile strength he did not remember. After a few failures no difficulty was experienced in obtaining quite sound castings, although they were of considerable size and complexity. The important matter to attend to was the casting temperature; the metal had to be just fluid enough to run into the mould, and if it was cast at a higher temperature cracks would appear. Possibly the difficulties that had arisen were due to insufficient care in adjusting the casting temperature.

Mr. R. F. **Graham** said he had made one or two experiments with the new alloy in his foundry, and he had happened to hit upon one or two of the alloys which were very successful. His foreman came to him one day and said that he could hardly cut the main runner, as it was so tough. After bending it thirteen times or so a hammer and chisel were applied, and finally a hacksaw had to be used to cut that part off. The alloys were, he thought, rather easy to cast, but it was very necessary carefully to watch the temperature, otherwise bad castings were obtained. He thought care should be taken in the making of the alloys, taking note of the temperature of each metal when mixing them to form the alloy. Some of the results obtained seemed unaccountable, perhaps owing to the haphazard way in which the alloys were allowed to form, and though chemically they might have exactly the same percentage of each metal, physically they might differ.

Mr. P. A. E. **Armstrong** said he was interested more or less in the processes of working the metal, such as pressing and turning, and had had considerable experience in aluminium working. He had endeavoured to make castings for electrical work and tried various percentages of alloy, including, roughly speaking, about 10 per cent. of zinc, and found that when the castings were machined whilst still warm, and up to about five hours after cooling, the metal dragged. It was almost impossible to get a proper thread. As other speakers had suggested, if the castings were allowed to season, the difficulty of machining was more or less overcome; nevertheless, he found that it was necessary to use lubricant, and the best results had been obtained with a composition of turpentine and paraffin. The usual shop soluble oil lubricant did not allow as high a finish to be obtained. He also discovered that the alloy would not allow casting to very close limits in sharp corners. After castings had been allowed to season for two or three weeks in store, it was found that cracks had occurred in the sharp corners of the casting, probably due to uneven shrinkage and resultant fatigue of the metal.

He had endeavoured to cast instead of to press, owing to the difficulties experienced with pressing in the usual way. Experiments were conducted with sheet metal working, the sheet containing about 10 per cent. zinc. He found that it was practically impossible to get pressings free from buckling and lapping until hot dies were tried. This he believed to be somewhat a new departure in the working of this alloy. The best results were obtained from dies that were raised to a temperature of about a blue heat; the exact reading he did not take. The sheet metal in every case took the shape entirely free from buckling or cracking. Experiments were then conducted in raising the temperature of the sheet, but good results were not obtainable. In nearly every instance the metal crumbled. This was probably due to overheating or to the exterior of the sheet becoming cool sooner than the inside, whereas in the case of the heated dies the longer the metal was in the die, therefore the greater amount of work placed upon the sheet metal, the hotter became the piece that was being worked. This, he was of opinion, set up a slow annealing process which evidently overcame the previous troubles. He also suggested that it was decidedly better from the workmen's point of view to handle cold blanks than heated ones.

Reverting to the subject of screws, he remembered that an endeavour had been made to screw a number of bars with a fine

(Mr. P. A. E. Armstrong.)

thread forty to the inch. When using 10 per cent. of zinc, trouble was experienced, but 5 per cent. zinc allowed this trouble to be almost entirely eliminated. He asked Dr. Rosenhain if experiments had been made regarding the conductivity of these aluminium-zinc alloys to electricity. His experience had been to the effect that the aluminium conducted a little better than the alloy, but the advantage was of a negligible quantity in ordinary or commercial work.

With regard to the question of abrasion, he considered this matter of undoubted interest from an electrical engineer's point of view, as considerable trouble has been experienced by him in plug work where direct contact was made between aluminium and aluminium. By using the aluminium-zinc alloy of either 5 or 10 per cent. this trouble was considerably lessened, yet he regretted to say it was still present; probably with a higher percentage of zinc and the copper this difficulty would be overcome, and he desired to refer this matter to Dr. Rosenhain for his attention.

The President, in calling upon Dr. Rosenhain to reply to the discussion, was sure it must be a great satisfaction to the members to have heard the men who were engaged in the practical making and using of the class of alloys referred to in the Report, such as Sir Gerard Muntz and Mr. Mills, speak so highly of the results of the authors' research. As he (the President) said immediately after the Report was presented by Dr. Rosenhain, it appeared to him to be the most valuable Report, so far as the results obtained were concerned, that the Institution had hitherto received in connection with the researches on alloys. It was evident that there was a great scope in the future for further improved results from the continuation of the researches which were now going on in the Ternary system, and which would no doubt in due time produce as valuable a Report as the one that had just been discussed. Some remarks had been made on the practical side, and some criticisms had been offered as to the way in which part of the research had been carried out. Such researches must always be carried out on purely scientific lines, but he thought it was one of the great merits of the research that had been carried out by the authors that they had never lost sight of the fact that the research was not a purely scientific one. The end in view was practical use and utility for those who subsequently had to make the alloys commercially. This Report would form the foundation of practical results which it was hoped would justify the researches which the Institution had undertaken.

Dr. ROSENHAIN, in reply, in the first place thanked the Meeting very warmly on behalf of Mr. Archbutt and himself for the very kind reception which was accorded to the Report both at the previous Meeting and on the present occasion. The valuable detailed criticism with which some of the members had favoured the Report was certainly a very welcome form of appreciation, and he thanked them at the outset for having gone into the whole question so carefully. Many points had been raised in the course of the discussion which he did not propose, however, to answer in detail that evening, but there were a few to which he would like to refer. Sir William White's words were words of kindness and encouragement which the authors valued very highly, and the remarks the President had made were very much of the same order. They made him feel that the efforts the authors had made to keep in view the practical side of things in the work they had undertaken were understood and appreciated by those who they hoped would ultimately benefit from it. He desired the members to understand—and one or two of the speakers had apparently failed a little in understanding it—that the Research was essentially a pioneer research into a system of alloys which, although they had been used by many people, had not previously been subjected to exhaustive or systematic study. One naturally had to choose between a large multitude of different methods of testing and experiment, and if in some cases the methods chosen were not quite those which other investigators would have selected, it was open to them to make similar experiments on their own lines and ascertain whether their results agreed with those of the authors. He did not contend for one moment that the authors' methods were the only ones or the best. They happened to be

(Dr. Rosenhain.)

the ones which, weighing one thing against another, they had decided upon as the most desirable, and he thought in detail he could justify most of them.

Sir Gerard Muntz in his remarks (page 449) referred to the behaviour of the alloy called Duralumin and the remarkable property of hardening which it possessed after a certain kind of heat treatment, and questioned whether that could be due, as was generally stated, to the presence of magnesium in the alloy, because Sir Gerard said that in his experience *castings* containing magnesium did not show hardening of that kind. It had however been proved that castings even of Duralumin did not show that kind of hardening; if Sir Gerard had rolled billets of that material he would have found that the phenomenon referred to did occur. But apparently that property of undergoing a slight change was not confined to the aluminium-magnesium alloys. Remarks made by Mr. Mills and by others since the Report was read had led him (Dr. Rosenhain) to take a view which he had not entertained when drafting the Report, namely, that there was probably a slight change in pure aluminium and in all aluminium alloys for the first few hours after they had been cast, and possibly again after they had been reheated. That brought him to the question of the ageing tests. When the authors stated in the Report that there was no change, what they meant was that there was no change which compared with the necessary experimental errors in such tests. The actual differences found were all of the order of a maximum of 1·8 tons, in the majority of cases being very little more than 1 ton, and he knew that duplicates, as the authors had been careful to state throughout the Report, varied by that amount frequently. The changes which aluminium appeared to undergo a short time after being cast seemed to suggest that, though it might be the fact that there was a real change, it was a change in the direction of improvement, and it remained to be shown that there was any deterioration afterwards. In the case of one of the alloys which he had had an opportunity of testing a very considerable time after it had undergone one of those spontaneous hardening processes, he could say definitely there was no change whatever; the alloy after two years was either as bad or as good as it was a few months after making. Whether that applied to the aluminium-zinc or aluminium-copper alloys it was impossible to say.

He thought if Mr. Harbord (page 472) and Mr. Law (page 476) would read the Report a little more closely they would find that the authors were very careful to state that their conclusions were based upon particular data. They had stated what those data were, and if anyone chose to generalize too widely upon them the fault was not theirs, because they had carefully stated the limitations of the conclusions they had drawn.

Mr. Fowler (page 455) had suggested that opportunities should be given to engineers to make trials of the alloys in various ways which the authors might suggest to them, and that the results of the trials should be available when the Reports were presented. He was afraid that was a counsel of perfection, because at the outset of the research the authors did not know enough about the alloys to make satisfactory suggestions—they would certainly not have the necessary information as to which of the alloys would be worth trial in time to allow Mr. Fowler or others to make the trials proposed. Such trials would have to follow the presentation of the Reports, unless the latter were to be unduly delayed. It was for the practical engineer and not for the experimental metallurgist to suggest the best use for the alloys. Mr. Fowler had asked for suggestions. Speaking not as an engineer but as interested in the alloys, he (Dr. Rosenhain) ventured to make a few. He did not know whether Mr. Fowler would be willing to build a railway bridge of the alloys mentioned in the Report. That was the kind of thing he would like to see tried. There was a possibility for the alloys in the direction of large structures. There was of course the question of price to be considered, which, however, he left on one side, because the question of price was a matter very often of time. But it was in those directions possibly that uses for the alloy would lie in the future, and also for such

(Dr. Rosenhain.)

things as the underframes of railway carriages and wagons and the chassis of motor-cars. In that connection he had amused himself by getting out some data as to the relative strength of rolled beams and of girders made of those materials as compared with steel.

Although Professor Arnold had said that static figures were of no use, he thought anyone who had to design bridges and beams would agree with him in thinking that after all reliance must be placed upon static data. He did not deprecate or underrate for one moment the importance of kinetic tests, as a glance at the Report would show, but he did not think they were the only things to be considered. Such tests gave information about the metals, and where those metals were used for machines the kinetic tests were of the utmost importance. But for large heavy structures, where the factors of vibration and alternating stress hardly applied, the matter was totally different. Therefore he thought there was still a great deal of fundamental importance about the static tests. The question of the strength of a beam had been worked out in the figures exhibited in the Table (page 485) on the assumption that the working stresses were similar to those of, say, a 30-ton mild steel. Seeing that some of the alloys had an ultimate strength of about 30 tons and the same order of yield-point that was met with in steel, that was a reasonable rough approximation. He was simply giving the members the basis of the data and they must take them for what they were worth. There were two or three ways of looking at the Table. First of all the calculations were based on the assumption that the material dealt with consisted of a rolled H or L section of corresponding dimensions, that is, the ratio of depth of flange and so on was the same. That was against the alloy in the comparison, because it would not be necessary to use so comparatively thick a web as in the case of steel, as in many cases the thickness of web was determined rather by rolling conditions than by questions of stress. What the authors had done was explained by the following Table:—

—	For Beams of similar cross-sections and			
	Equal Dimensions.	Equal Weight.	Equal Strength.	Equal Stiffness.
Ratio of linear dimensions of cross-section of beam for alloy to ditto for steel	1	1·55	1	1·35
Ratio of weight of beam for alloy to ditto for steel	0·415	1	0·415	0·757
Ratio of strength of beam for alloy to ditto for steel	1	3·74	1	2·46
Ratio of deflection of beam for alloy to ditto for steel	3·33	0·574	3·33	1

They had calculated in the first line of figures the linear dimensions of the cross-section of the beam of the alloy and the ratio of that quantity to the linear dimensions for steel. Where the two beams were of equal dimensions the weight of beam for the alloy was much smaller, the ratio of the weight of the beam for alloy to the weight in steel being 0·415. The strength, using the same working stresses, was the same, and the deflection, which he would define as the increment of deflection due to a given increase of load, once that load was already applied, was three and a half times as large. Taking a case which was really fairer to the alloy, where there was a beam of equal weight, owing to the lower density of the alloy it would be a beam of considerably larger cross-section; in fact the linear dimension was 1·55 times that of the linear dimension of the steel or the inverse of the square root of the ratio of the densities. The weight of the beams was equal in that case, and the strength of the beam of the alloy for equal working stresses was 3·74, or about 3¾ times that of a steel beam of the same weight.

Under the heading of "equal weight," the beam of alloy showed a deflection of a little more than half—0·574, a result in which the greater depth and greater stiffness more than counterbalanced

(Dr. Rosenhain.)

the lower elastic modulus. Applying that result, and reducing the weight in proportion, the same strength would be given for an enormous saving in weight and great increase of stiffness in the structure. With beams of equal strength the same results were obtained as with beams of equal dimensions.

Finally, for equal stiffness linear dimensions of 1·35 were obtained, but it was dependent upon the lower elastic modulus of the alloy. In that case the figures for weight and strength were respectively about $\frac{3}{4}$ and $2\frac{1}{2}$, the deflection of course being equal. It would be seen therefore that when those alloys were used not merely as the tensile members of a structure, but in the form of beams and girders, their relative value was enormously higher than was indicated by their relative specific tenacity. And in addition to that it must be remembered that what applied to beams applied also to struts. In a girder of large dimensions the beam strength of the alloys as indicated would apply very largely to the compression members, and therefore the limiting span of a bridge built of those alloys would be enormously larger than the limiting span of steel. Even if a high tensile steel were used, the same effect would not be obtained, because if a beam were made of it, its moment of resistance was only larger in direct proportion to its tensile strength or to the working stress applied; and none of the effect of spreading the material out over a larger surface and getting a larger moment of resistance, as was obtained from the lighter specific gravity of the alloys, would be obtained.

Mr. WILLIAM H. PATCHELL inquired whether Dr. Rosenhain had taken the wind pressure into account.

Dr. ROSENHAIN replied in the negative. He had not, he said, considered it in detail in that way at all, but wind pressure would be largely a question of the arrangement of the material. In many cases the material could be arranged so as to expose as little surface to the wind as possible, although that was not so in the case of a solid rolled girder. In such a thing as the underframe of a railway carriage a very much lighter chassis would be obtained, and of course the wind resistance would be no greater then than in the other case.

Mr. PATCHELL thought it would enter into the bridge problem.

Dr. ROSENHAIN said there was no doubt it would enter into the bridge problem, and for that and similar reasons he had not ventured to calculate out on the well-known formulæ the limiting spans for bridges built of those materials. It would be better that such a calculation should be left to an experienced bridge-designer. It would be quite an interesting one. The specific tenacity measured another fact which might be put in another way. If a bar of the material were suspended vertically, the specific tenacity measured the length of the material which could be hung up before it broke under its own load. That meant that a wire rope of that material could be made of enormously greater length for a given working stress than it could be made of steel. But the alloy had not the property of steel, which obtained very high tensile stress on wire drawing. He did not suggest that mine ropes could be made of such materials, at all events without further investigation, because corrosion and fatigue entered so much into the question. Professor Arnold's test was, in his opinion, a very good one for determining the behaviour of material intended for mine ropes.

Some criticism had been levelled by Mr. Leonard Archbutt and other speakers at the corrosion tests, but he desired to point out that the first to criticize those corrosion tests were the authors themselves in their Report. The authors stated that the results of the corrosion test were unsatisfactory and preliminary, but even then he thought they might be defended against some of the charges which had been brought against them. First of all, the suggestion had been made that because the metals had to be protected from the corrosive action of wood and rope they were necessarily bad. He would like to point out that they were endeavouring to get practical results from a very small quantity of metal. If a plate 20 feet square were held up by rope or wood at the edges the effect would not be the same; the loss of weight per

(Dr. Rosenhain.)

square foot would only be minutely affected. But when it came to a question of measuring the loss by corrosion on a 3-inch square, and something like 10 per cent. of that area was allowed to undergo special corrosion due to causes which would not exist in a riveted structure consisting entirely of that metal, then an unfair result would be obtained. The authors therefore were perfectly right in protecting the specimen from corrosion at the edges, because a result was obtained per square foot from a surface of only 3 inches. It was quite true that that was a very small surface. They would like to have worked with a 3-foot plate, but the physical difficulties connected with so large a section were so great that he was afraid it would be beyond their power to do it. The proposal to use tensile test-pieces for corrosion showed that they were alive to the imperfection of such corrosion tests where the measurement was taken by loss of weight.

Mr. Harbord (page 475) had questioned the reference to Muntz Metal and Naval Brass, but those alloys and those mentioned in the Report were strictly comparable. The tests on Muntz Metal and Naval Brass appeared in an Appendix to the Ninth Report. They were carried out in exactly the same manner and almost by the same workers as the tests on the aluminium-zinc alloys, and therefore they were strictly comparable.

Passing to a consideration of the questions raised by Sir Frederick Donaldson (page 458), that speaker had suggested that the authors' casting temperatures were too low for foundry purposes. That point had already been answered by several practical foundrymen, who had said that they found it necessary to adhere to very low casting temperatures, and that they obtained successful castings by so doing. That also supported the view which was put forward by the authors tentatively, and acknowledged by them to be put forward on the basis of such alloys as were exhibited, that it was possible to get sound castings out of the alloys. They were confirmed in that view by the practical experience of several aluminium founders who were present at the Meeting. With regard to the actual casting temperatures and the figures quoted by Sir Frederick Donaldson, as a matter of fact that gentleman had brought forward a number of ternary alloys which happened to coincide with some of those the authors had already investigated as a portion of the material for what they hoped would form part of the Eleventh Report to the Committee; and he intended to anticipate a few of the data by giving them in comparison with Sir Frederick Donaldson's results. For instance, Sir Frederick Donaldson had compared an alloy containing 19 per cent. of zinc and 1 per cent. of copper cast at various temperatures with the authors' alloy No. 20, containing 20 per cent. of zinc. He (Dr. Rosenhain) could give a better comparison than that, namely, an alloy of 20 per cent. of zinc and 1 per cent. of copper, which was not described in the Tenth Report. It was found that such an alloy gave a yield-point of 7·24 tons, an ultimate stress of 14·6 tons per square inch, and an elongation of 3·5 per cent. on 2 inches. Those figures represented the higher of two duplicate tests, each of which was within 1 ton of the other, as they always were unless they were exceptional. That compared with the best results given by Sir Frederick Donaldson for a casting at 800° C. of 7·8 yield-point, 13·1 ultimate stress, and an elongation of 4 per cent. The authors' alloy was at least as good, and the ultimate stress was 1½ tons higher.

Then Sir Frederick Donaldson gave a sand-casting alloy containing 15 per cent. zinc and 1 per cent. copper (page 461), the figures in connection with which were 4·8 yield-point, 8·6 ultimate stress, and 4·5 per cent. elongation. Against that he (Dr. Rosenhain) desired to compare the authors' 16 per cent. zinc and 1 per cent. copper alloy, which gave 5·32 yield-point, 12·68 ultimate stress, and 7 per cent. elongation. The difference was apparently due to the fact that Sir Frederick Donaldson seemed to think it necessary to cast at a higher temperature. Similar comparisons applied to the chill-castings, the results of which were higher in the authors' alloys than in Sir Frederick's. In order to test the matter further, the authors had thought it wise between the last Meeting and the present one to make some preliminary experiments on the effect of casting temperatures on some of the alloys. They had accordingly prepared a 20 per cent. zinc and 1 per cent. copper alloy in small

(Dr. Rosenhain.)

quantity and cast a number of chills. These were turned up and tested in the ordinary way, the results being given in the following Table:—

Influence of Casting Temperature—20/1 *Alloy.*

Casting Temperature.		Yield-Point.	Ultimate Stress.	Elongation on 2 inches.
°C.	°F.	Tons per sq. in.	Tons per sq. in.	Per cent.
850	1562	7·57	10·02	2·5
800	1472	7·78	13·76	4·0
750	1382	7·63	14·06	3·0
700	1292	7·63	14·16	4·0
650	1202	7·95	13·80	5·0

The casting temperature was given in the left-hand column. It would be seen that at the 850° C. casting temperature the figures were very low indeed; at 800° C. they were slightly higher; by the time 750° C. was reached a result was obtained which was very nearly the best of all. It was interesting, and perhaps it would be instructive to Mr. Harbord to see that from 750° to 650° C., which was a very small range of casting temperature, the results which were given in full were in such close agreement. The Table as it stood was, he thought, fairly conclusive as showing that at so high a casting temperature as 850° C. the metal was completely spoiled. 800° C. was not so injurious, but a lower temperature gave a better result, particularly in regard to elongation. A great deal depended upon the particular metal being cast. If intricate or very narrow and thin castings were being cast it was necessary to pour fairly hot, but that was undoubtedly done at the expense of the mechanical properties of the resulting casting.

With regard to the question of rolling temperatures, he thought Sir Frederick Donaldson had slightly misunderstood the authors' statements, possibly because the wording of the advance proof was not quite as explicit as it might be. Their contention that a rolling temperature generally below 400° C. (752° F.) was necessary to ensure good rolling, applied principally to the higher alloys containing 25 per cent. of zinc and 3 per cent. of copper. Alloys containing 15 per cent. of zinc and lower than that could be rolled, as Sir Frederick Donaldson had said, at very much higher temperatures.

Another point to be taken into consideration was how the temperatures quoted by Sir Frederick Donaldson had been measured. Was a measurement taken of the furnace temperature, or was the temperature of the billet itself measured? The authors had dealt with 3-inch billets, and measured the temperature by setting on the top of them in the muffle a saddle made of aluminium, or of aluminium containing a little zinc. This saddle rode on top of the billet, and there was a groove drilled in it, into which was inserted a thermo-couple in a small silica protector. By leaving the saddle on the billet in the muffle and taking the temperature without displacing it, the authors obtained the approximate temperature of the billet. The exact temperature of the billet could only have been obtained by getting the thermo-couple right into it, but the approximation was much closer than if the temperature had been taken at some point in the furnace more or less near where the billet was lying. He therefore thought the authors' temperature measurements were rather more definite than the rolling temperatures usually quoted. There again they could claim results strictly comparable with those quoted by Sir Frederick Donaldson, who referred to an alloy of 10 per cent. zinc and 1 per cent. copper hot-rolled to $1\frac{7}{8}$ inches diameter, with a yield-point of 4·9 tons per square inch, an ultimate stress of 10·6 tons per square inch, and an elongation of 25 per cent. The authors' alloy of the same composition rolled to $1\frac{1}{4}$ inches gave 6·88 yield, 13·24 ultimate, and 28 per cent. elongation. In a similar way the authors could duplicate several of Sir Frederick Donaldson's results, showing generally that the pure zinc alloys which they had used were decidedly superior to the commercial zinc alloys used by Sir Frederick Donaldson. There could be no doubt from a comparison of the results, quite apart from the figures given by Mr. Archbutt, that the pure zinc alloys were superior.

(Dr. Rosenhain.)

Mr. Harbord had asked the nature of the impurities in the zinc (page 472). In the particular sample of commercial zinc which the authors bought in the open market they found 0·019 per cent. of iron and about 2 per cent. of lead. There was no doubt from their own experiments that castings made with zinc containing lead were subject to much more severe corrosion in sea-water than those made with pure zinc. How high the degree of purity must be in order to get those better results they were not prepared to say; that would require another research which they had not yet carried out.

Then he desired to thank Professor Arnold for his exceedingly kind and appreciative remarks (page 464). The Ninth and Tenth Reports were naturally the lineal descendants of the Eighth Report. They had only been modified here and there, because the scheme laid down in the Eighth Report was of so comprehensive a character that it was impossible to improve upon it very radically at present. The investigators hoped in future to be able to use very much larger quantities of metal, and, thanks to the generosity of Sir Julius Wernher, they had a much larger establishment at their disposal, and he thought they might be able to make castings large enough to satisfy even Mr. Harbord, if they thought it necessary. They had a 3-ton crane. Professor Arnold had made some remarks on the question of correlation of the static elastic limits with the Wöhler tests. The authors hoped to make such a correlation, but they did not have any Wöhler tests made. Direct alternating-stress tests had been made, but the results obtained were so remarkably abnormal—so very low compared with the static elastic limits—that the authors did not attach very much weight to them. There seemed to be some factor about them, possibly due to resonance or to the low elastic modulus of the alloys, which tended to affect the results, but they quite saw the desirability of trying to correlate them with the Wöhler tests. He feared, however, that Professor Arnold had somewhat stretched a point when he compared his alternate-bending test with such alternations of stress as a connecting-rod would endure. He did not think that a connecting-rod, in any reasonably designed engine, would be bent through $\frac{1}{8}$ inch in 3 inches at every stroke, which was the figure obtained in

Professor Arnold's machine, or something very like it. He was not suggesting this as a criticism of Professor Arnold's test, because that test was a valuable one and gave interesting results, but it certainly was not quite the kind of thing that a connecting-rod was exposed to, except as to the rate of alternations. He had already referred to Professor Arnold's remarks that the static tests were of minor importance. No doubt for machinery kinetic tests were advisable, but for structural pieces they were not quite so important.

Mr. Mills (page 468) had suggested that the authors might hope to get something better than the 25/3 alloy. He hoped that would be so. If it was found that the hardening action of magnesium with subsequent heat treatment was as much applicable to the aluminium-zinc alloys as it was to the aluminium-copper-manganese alloys, it ought to be possible to double the tensile strength of the rolled alloys at all events, although, as he had already pointed out, such an action was not to be looked for in castings. It would be interesting to see whether the view that the aluminium-zinc castings warped was borne out by the experiments the authors proposed to make. It was intended to have castings of a somewhat complicated shape made, to measure them accurately and to lay them by, and repeat the measurements at intervals in order to ascertain what changes of shape occurred. He hoped it would be possible to do them with castings made of pure aluminium and zinc and also of the impure varieties.

Mr. Mills had criticized the authors' formula of "specific tenacity." He quite sympathized with that gentleman that if he had to deal with people who did not understand technical terms it might be necessary to modify them or to use terms which were easily understood, but he did not think that for purposes of accurate technical comparison and for the purposes of scientific discussion such a definition as Mr. Mills proposed would be at all satisfactory. It was after all only a question of dividing the figures which had been given in the Report by 3·16. If that was done, an alloy would be obtained not of a specific tenacity of 250 but something like a specific tenacity of 80, and if Mr. Mills' customers asked for an 80-ton alloy he would be no better off under those circumstances

(Dr. Rosenhain.)

than if the other figures were used, except that they would be so much nearer the truth that it would not be so easy to show them how ridiculous their demand was. Specific tenacity was not a property "per square inch." The authors had never spoken anywhere of 250 tons per square inch; they had spoken of a specific tenacity of 250, and had pointed out that that was a property of the material quite independent of its dimensions. They had for the sake of illustration explained it as the breaking load of a bar, or, as Mr. Mills called it, of a disk of a certain cross-section, but that was only one way of putting it. The reason for choosing that particular formula was to make it comparable with other quantities, such as specific conductivity and specific resistance, which were measures of the specific property of the material independent of its dimensions. The members would recollect that specific conductivity was the conductivity of a cube 1 centimetre on the side. In coining a new term, as the authors had done, they had endeavoured to adhere to something like a sound physical definition. The quantity was actually measurable in tons, divided by a cross-sectional area dependent on the density of the material. It was perfectly possible for commercial purposes to introduce some other term based on such a standard as Mr. Mills suggested, but he hoped that gentleman would not call it "specific tenacity," because it was not that.

Mr. Harbord asked several other questions with which he thought he had dealt. With regard to the duplicates of tests, he thought in most cases the errors of the duplicates had been stated wherever they were appreciable. In the great majority of cases they were not, and in the two or three cases to which Mr. Harbord referred they were stated because they were so abnormally large. Unfortunately the obvious course of repeating some of the tests which gave divergent results was not possible, because the material was not available. Even as it was, it was necessary in many cases to make separate heats of the metals, and the authors did not succeed in repeating them quite exactly. That was why alloys 19 and 20 existed. They would never have deliberately made those two different alloys. They were intended for repeats, but as they differed by nearly 1 per cent. they preferred to ascertain that the tensile tests of 19 and 20 were within experimental error of one another.

With regard to the dimensions of the test-pieces, when it was found that bars were being dealt with the section of which was too small to accord with the Engineering Standards Committee's test-piece of 2-inch gauge length, it was decided to adhere to the law of proportional test-pieces, which gave comparable results so far as the ultimate strength was concerned. That the results were not comparable with regard to elongation the authors were well aware, and they had pointed out the actual gauge-length on which each test was based. The expense of making 8-inch test-pieces was very great compared with that of making 2-inch test-pieces, and consequently the authors had contented themselves with the latter, which he thought had been used throughout the previous researches. 8-inch test-pieces had only been made of alloys which appeared to be of special importance in the rolled condition, and if those were compared Mr. Harbord would see that they were in very close agreement with one another.

Mr. Law had asked for more, which was a very great compliment indeed to the authors. He hoped that gentleman would get it in time, but of course such tests as those referred to in the Report took a long while to carry out. The only remark made in the course of the discussion which he found it difficult to understand was that made by Mr. Armstrong with regard to the difficulty of machining the alloys. Several hundred test-pieces had been screwed and threaded in the engineering workshops of the laboratory, and there had never been the slightest difficulty in doing it. Not only that, but it had been possible in the case of the harder alloys to do so without the use of any lubricant at all. He thought it was a question of the mere knack of handling the things. As he pointed out at the last Meeting, turnings of great length could be obtained with the greatest ease without any lubricant at all. He was obliged to admit, however, that they were obtained from the rolled bar and not from the casting. Turnings could be obtained from the

(Dr. Rosenhain.)

castings, but not in such long lengths, and they could not be so easily obtained. He found it very difficult to understand why Mr. Armstrong met with such difficulty in machining the metal. That Mr. Armstrong would meet with difficulty in stamping the metal cold was what he would expect from its general mechanical properties. It was interesting to find that it was easier to stamp with a hot die than to stamp the metal when previously heated. When the metal had been previously heated it flew to pieces, much in the same way that the authors had shown in the course of their experiments at the last Meeting. Either the metal was very much too hot or the speed of the die was too fast. With slow stamping it should be quite possible to get the metal to take the desired shape. With drop stamping it was naturally impossible to regulate the speed; in that case the temperature must be adjusted and kept fairly low. He imagined that a temperature like that of boiling water would be enough to give the desired effect.

A great many other points had been raised in the course of the discussion, but he would not attempt to reply to them at the present moment, and in conclusion he again thanked the members for the very kind way in which they had received the Report.

Communications.

Mr. HERBERT J. BUBB wrote that the Aluminium Castings Co., Ltd., of Greenock, had for some time found that the bad reputation with which alloys of aluminium and zinc were credited was not due to the presence of zinc in itself, but largely to the impurities in the metals used, and more especially those in the zinc itself. With the considerably improved quality of commercial aluminium at present, and the use of the purest virgin spelter available, his firm had found very marked differences indeed in the ultimate strength and toughness of their alloys, and also in their retention of this quality after years of service. When ordinary brands of spelter of no special purity were employed, the strength of the resultant alloy, in castings, undoubtedly diminished very rapidly with time and service, but this fault appeared to be, if not entirely, at least considerably overcome by the special selection of materials employed. It was on this account that they had taken a different stand to the American authorities, in that they recommended without hesitation the use of aluminium-zinc-copper alloys in preference to those of aluminium and copper only; both greater strength and greater ease in machining and subsequent treatment were experienced and the deterioration was no longer to be feared.

Sir ROBERT A. HADFIELD (Member of Council) wrote that his own experience had been confined to iron alloys, and he found this one metal with its alloys demanded all his time and attention. Therefore he was not able to offer remarks of any value upon this excellent Report. From personal experience in alloy research work he knew it was not an easy matter to carry through a research of this kind. There were often so many inconsistencies to be reconciled, so many difficulties to be overcome, that one sometimes despaired of concordant results. The authors were therefore to be heartily congratulated upon the successful work they had put before the Institution.

As regards the ageing tests (page 354), he had noticed somewhat similar behaviour in certain alloys of iron with manganese and nickel. The material at first seemed to be excellent, but after a lapse of time "degradation" occurred. The ageing noticed in his specimens was, however, not so pronounced as that referred to by the authors. He did not notice any tests mentioned in the Report on material water-quenched, and should have thought some of the most interesting amongst the alloys produced would have offered results of possible practical value when so treated and their physical properties then examined.

Reference was made to some of the alloys breaking up into coarse powder by blows (page 416). It might be interesting to mention a specimen of an alloy of iron (95 per cent.) and manganese (about 4 per cent.), which he made many years ago. Such an alloy was so brittle in its cast form that it could be powdered almost like

(Sir Robert A. Hadfield.)

sandstone. Fig. 109, Plate 22, (taken through a Carl Zeiss "Microscope for examining fractures") represented these curious crystals or fragments under these different magnifications, 150, 300, and 750, of the surface of one of the fragments, slightly polished and etched.

Mr. F. C. A. H. LANTSBERRY (Birmingham) wrote that the results shown in the Report should go far in dispelling many of the illusions regarding aluminium alloys generally and aluminium-zinc alloys in particular. It had been shown that the alloys had a greater capacity for resisting shock and corrosion than they had been given credit for of late years. For many years aluminium had been suffering from being overrated in its infancy, when too much was expected of it, and this fact had undoubtedly hindered the progress of this most useful metal. In many ways it would be found that perfection had not been attained in the light alloys, but could it be claimed that steel, brass, and bronze were perfect? Nevertheless these materials were largely used in spite of their imperfections, the effects of which we were slowly learning to obviate. It would be necessary to study the corrosion and erosion of the light alloys under varying conditions, and in this connection it would be extremely useful if the authors would compare the corrosion of these alloys with that of structural steel. Such a comparison would probably show the alloys in a still more favourable light; but, even if it did not, methods of protection could easily be evolved just as has already been done in the case of iron and steel by painting, plating, and enamelling.

One of the most remarkable phenomena about the aluminium-zinc alloys was the apparent adverse effect of increased work, particularly on the alloys containing over 20 per cent. zinc. So far as the writer was aware, this behaviour was unique, and it would appear that in view of the widespread belief that it was exceedingly difficult, if not impossible, to roll alloys containing over 15 per cent. of zinc, the authors were induced to bestow particular care on the annealing after the first operation, that is, rolling down to the $1\frac{1}{4}$-inch bars. In this way the effect of work was not additive to the same extent as it was in the case of the lower zinc alloys. The observation that the effect of work was to some extent permanent, and not entirely removed by subsequent heat treatment, was quite parallel to the case of steel, in which there was no doubt that the beneficial action of preliminary mechanical treatment persisted through the whole of the subsequent history of the steel.

Mention had been made of the peculiar properties of alloys containing magnesium. Wilm observed that aluminium-copper-manganese alloys to which amounts of magnesium even below ½ per cent. had been added gradually increased in strength after heating to 500° C. and cooling fairly rapidly. The alloy "Duralumin" was the direct outcome of this observation, but numerous tests made by the writer had failed to reveal in it the presence of more than traces of magnesium. It would appear therefore to be somewhat early in the day definitely to assign the cause of this peculiar effect to magnesium. A glance at Table 4 (page 352) would show that in every case the mechanical properties of aged alloys were superior to those of the freshly made alloys, and yet they had received no form of heat treatment. The experiment of trying to accentuate this effect would appear to be one worthy of trial. Another important question to be answered was: "To what extent could this added strength be relied upon as permanent?" Tensile tests made by the writer on a sheet of duralumin 0·082 inch in thickness showed that it had a fairly definite yield of 50,000 lb., an ultimate stress of 66,000 lb. per square inch with an elongation of 2 per cent. After boiling in water for 4 hours it had no definite yield-point and broke under a stress equal to 58,500 lb. per square inch. A wire 0·057 inch diameter broke under a load of 180 lb., but after annealing at 260° C. for half an hour it broke under a load of 160 lb. After annealing at 260° C. for half an hour the strip broke under a stress equal to 51,200 lb. per square inch. These were the results of single observations made on a commercial testing-machine and required confirmation. They were of interest, however, in showing that such artificially hardened alloys broke down under quite mild thermal treatment, and that easily acquired properties were lost with almost equal facility.

Mr. JAMES MCKECHNIE wrote that he had read with very great interest the Report by Dr. Rosenhain and Mr. Archbutt. One of the chief desiderata of all metallurgists had been to produce alloys that were strong and reliable, and most of the attempts that had been made with this object on metals with low specific gravities had been more or less disappointing to engineers generally. The writer had had considerable experience with aluminium alloys, and it would interest the authors to know that for several years Messrs. Vickers had used an aluminium-zinc alloy with very satisfactory results. Using spelter of 99·5 per cent. purity, and alloying about 30 per cent. of this with aluminium, they had obtained tensile tests of about 18 tons per square inch from sand-castings. This alloy they had found very useful for a large number of purposes, but had had no experience with it, either in the direction of hot rolling or of hammering. The material in question, however, could be very readily machined, and presented a very good finished appearance.

During their investigation of aluminium alloys his firm had come across one known by the name of "duralumin," which had been brought out by Herr Alfred Wilm, a German metallurgist, of Schlachtensee, Berlin. The physical properties of this alloy were so remarkable that they decided to prosecute an extended investigation of it. It had now been known to them for upwards of three years, and material which had been in use for that length of time had shown no signs of deterioration, either physically, microscopically or chemically. Moreover, the results of tests recently carried out on such material indicated that it was as good now as it was when first manufactured. It might prove of interest if the writer furnished a brief description of the treatment the alloy underwent in order to produce the results that it was capable of giving, the more especially as these results were obtained by a combination of physical and thermal treatments, involving close and careful attention to details.

Duralumin consisted of an alloy of aluminium with from 3·5 to 5·5 per cent. of copper, 0·5 to 0·8 per cent. of manganese, and 0·5 per cent. of magnesium. Its specific gravity varied according to the alloy, and lay between 2·75 and 2·84. Its melting-point was

650° C. (1,202° F.). Its hardness had been determined by the Brinell method. Usually a ball 10 mm. in diameter was used; but in order to determine the hardness of very thin plates, a 2½ mm. ball was used. The load was 62½ kg.; therefore $P = 1000d^2$.

Soft cartridge brass strip tested by this means showed a hardness of about 60. It was well known that cold-working increased the strength of ductile metals at the expense of the elongation and hardness. Duralumin, with a specific gravity of 2·79 in its annealed state, gave under tensile strain 16·75 tons per square inch with 17 per cent. elongation on 2 inches. The hardness was about 70. By cold-rolling from 7 mm. to 1 mm. in thickness the tensile strength was increased to 34 tons per square inch, whilst the elongation was reduced to 3 per cent. Thus by cold-working duralumin which had been annealed, degrees of strength had been obtained which reached the highest limits of the strongest of other high-aluminium alloys. It might, however, be hardened by quenching similarly to steel; and herein lay the difference between duralumin and most other high-aluminium alloys. Unlike steel, however, it mattered but little whether the hardening process was applied to the annealed material or to material which had been annealed and afterwards cold-worked by rolling, forging, etc. By observing the rules laid down for hardening, greater strength and hardness were obtained than was possible by cold-working the annealed material alone. For the alloy under consideration this hardening process increased the tensile strength to 26 tons per square inch and the hardness to 110. It not only increased the tensile strength and hardness, but also the elongation. In the sample under consideration the elongation was increased from 17 to 23 per cent., or 6 per cent. more than was given in the annealed material. In one of the duralumin alloys the degrees of hardness were increased to 174, with a tensile strength of 39·4 tons per square inch and an elongation of 3 per cent. Should it be intended to work the metal hot, or if it should be found necessary to anneal it during the process of working it into various shapes, the metal was best supplied annealed, as such heating removed the strength and hardness obtained during what might be called the "treating"

(Mr. James McKechnie.)

process. The treating should then be performed on the finished article, and where necessary—that is, where greater hardness and strength were required—the metal might be further cold-worked subsequently to the treating.

In the heat treatment of duralumin it was necessary to adhere very closely to the prescribed temperatures, and means must be taken to ensure that the correct temperatures were employed during the working or subsequent treatment. A temperature of 150° C. (302° F.) would cause a great falling off in tensile strength, whilst a temperature of over 410° C. (770° F.) gave a very considerable increase in strength after cooling. Temperatures higher than 510° C. (950° F.) did not come into the question at all in working, so that the entire treatment lay within limits which did not produce colours that could be distinguished by the eye alone. The heating treatment was best carried out in baths, containing mixtures of suitable salts, heated externally, thermometers or pyrometers being installed and means taken to ensure that the correct temperatures were obtained. Strangely enough, upon heating and quenching duralumin for the final treatment, the material at first showed no increased hardness. After the expiration of an hour its hardness and strength increased. During the next half-hour this increase became more rapid, afterwards becoming more gradual again until the sixth hour after treating. The hardness continued to increase for about 48 hours, after which no change took place. This "rest" hardness, after hardening treatment, was one of the most remarkable properties duralumin possessed. It was very convenient for a number of reasons; for example, as the metal was not harder immediately after treatment than it had been before, any buckling or distortion could be removed, plates and sections could be straightened, and whatever shape was given to the material within one hour of the treating process would be retained. Should the material be harder than might be required, it could be "let down" by heating between 100° and 150° C.

From the foregoing figures it would be seen that, according to the alloy used and the treatment to which the finished material was subjected, results could be obtained varying from 16 to 39 tons per square inch, with a hardness of from 70 to 174. The modulus of elasticity from one of the alloys, according to the calculations of the Aix Technical College, was 700,000 kg. per square centimetre, whilst those of the Neubabelsberg Centre for Scientific Research gave 730,000 kg. per square centimetre, the shearing strength of the same alloy being given as 30 kg. per square millimetre, or, say, 19 tons per square inch.

Regarding the influence of the individual constituents of the alloy, from the systematic tests commenced by Herr Wilm in 1903, it would appear that the use of magnesium alone, in suitable proportions, gave increased hardness to the material if the same were laid aside after being treated at the correct temperature, the percentage added being practically the same whether heavy metals were added or not. The further alloying with copper and manganese raised the point from which the increase in hardness began, namely, to about 110, whilst the hardness of aluminium alone was not over 40.

Duralumin has already been used for a large number of purposes with very satisfactory results, both in this country and abroad. It was at present being largely employed in the structural parts of airships and aeroplanes, for artificial limbs, cartridge cases, horseshoes, lances and stirrups, and for many other commercial purposes; in fact it could be used with advantage for all purposes where financial or constructional reasons made light weight with great durability and strength a consideration. It was unaffected by mercury; it was non-magnetic; withstood atmospheric influences, and was but little affected by sea or fresh water or sea air. It was capable of taking a very high polish, which was permanent. It gave a very clear sound when struck, and was being used in many parts of Germany for bells for telephones.

In conclusion, he would like to refer to the remarks made by Sir Gerard Muntz upon this metal in the Discussion (page 449). The material he used must have been in some way or other improperly treated. As a matter of fact, it could be hot-worked and remained perfectly ductile. It was usually subsequently cold-rolled, or drawn, with annealing between such operations, and still retained its ductility. When completed for use, it was thermally

(Mr. James McKechnie.)

treated, and, as would be seen by a reference to the writer's remarks (page 502), it was this after-treatment that affected the hardness of duralumin which it increased, as well as the ductility and tensile strength of the material.

Dr. RICHARD SELIGMAN wrote that, when discussing the Eighth Report, he urged the importance of investigating without unavoidable delay the properties of the aluminium-zinc-copper alloys, because then, as now, more aluminium was used in the form of these alloys than in any other form. As a step to that end, the present Research was particularly welcome to the aluminium industry, especially as the Appendix (page 441) showed that the ternary alloys were already under examination. For the industry with which the writer was connected the questions raised in the Tenth Report, which were of most immediate importance, were three in number: the comparative lack of brittleness of the alloys containing 10 to 20 per cent. of zinc; the possibility of rolling and drawing these alloys; and their liability to corrosion.

He thought that the authors had been entirely misinformed as to the reason why alloys with more than 13–14 per cent. of zinc had not been used heretofore. They ascribed this (pages 355–6) to the high specific gravities of these alloys, but he did not believe that this factor had, with rare exceptions, ever entered into the question. The reason had undoubtedly been that manufacturers had known by experience that, if they went above the zinc-content named, their alloys became brittle under vibration, and, although this was of less importance, they could not be rolled and drawn. By the assistance rendered by this Report in avoiding these difficulties its immediate value must be measured, because it was obvious that the more zinc that could be used the cheaper these alloys became. As the strength increased at the same time, the industry would be doubly benefited if as a result of this Report more zinc could be used. It must be remembered, however, that these alloys were required almost exclusively for castings and sand-castings for the automobile industry. Resistance to shock and vibration was therefore of prime importance.

In the early days of motor-cars these castings were continually failing, so much so in fact that many engineers thought that it would be necessary to abandon them in favour of some heavier but more reliable material. However, by reducing the zinc-content, and thereby sacrificing to a certain extent the rigidity of the alloys, the difficulty was largely overcome, and although breakages frequently occurred, their proportion to that of the enormously increased number of castings in use was now small. Although the authors of the present Report were of the opinion that the fears which had been entertained as to the alloys containing higher percentages of zinc were not well founded, it did not appear from the Report that their view was supported by evidence. They apparently confined their dynamic tests to the alloys in wrought form; and as to these there had been no generally expressed fears, chiefly because there had up to the present been practically no demand for these alloys in the form of sheet and rod. This question must therefore still be considered as open, and it was very much to be hoped that in their examination of the ternary alloys the authors would not fail to extend their dynamic tests to the more important at least of the cast alloys. Such a step would largely enhance the value of their work to the metal industry, and might enable them to answer the question finally.

With respect to the rolling and drawing of the higher alloys, the work of the authors undoubtedly marked a very large step forward. The opinion was certainly current among those most intimately connected with the subject that it was quite impossible to roll some of the alloys which the authors succeeded in rolling. The late Mr. Harvey, who probably had more experience of this particular question than any one else, thought that the limit of workable alloys had been reached with a zinc-content of 13 per cent. and 3 per cent. of copper. By showing that a careful temperature control would enable the roller to handle the much stiffer and cheaper alloys successfully, the authors had undoubtedly rendered the aluminium industry a great service, although possibly some time would elapse before use was made of their discovery. At present almost the only use to which these alloys were put in

(Dr. Richard Seligman.)

the wrought state was for the manufacture of the fuses on shrapnel, for which purpose an alloy containing 12·3 per cent. zinc and 0·65 per cent. of copper was introduced from Germany about seven or eight years ago. The information placed at their disposal by the authors should enable manufacturers to find other uses for these alloys. They should serve admirably for the panelling and mouldings on motor-cars, railway carriages, etc., for which pure aluminium was largely used, and was at one time used proportionately still more widely. The use, as was well known, was checked by the increase in price of aluminium, and the realization of the fact that the "specific tenacity" (to use the term happily coined by the authors) of steel was greater than that of aluminium. Some of the alloys described in this Report appeared to have a materially higher specific tenacity than the steel which was used for this purpose, whilst the addition of as much as 25 per cent. of zinc should so affect the cost of these alloys that the ground lost to steel should ultimately be regained.

As to the third question, the liability of these alloys to corrosion, he entirely agreed with the authors' view that loss of weight was not a safe criterion. With aluminium and its alloys corrosion was as often as not signalized by increase of weight; gain and loss might also occur simultaneously and mask one another. Except where the action of a liquid which actually dissolved aluminium was concerned, the weight test was frequently most misleading. The new test which the authors proposed was certainly an improvement, but, in the writer's opinion, an experienced eye, supported in some cases by a microscope, was the surest guide as to the resistance of aluminium to corrosion, except as aforesaid. It must be remembered that the corrosion of aluminium was almost always local, and that a loss of weight which was apparently negligible might be due to complete perforation of a sheet which would render it absolutely unfit for use in the particular solution under examination. The same difficulty might arise with the tests proposed by the authors. It seemed a pity that in these Reports the authors should confine their attention to the action of sea-water. This was certainly a severe test, but it was no guide whatever to the behaviour of the alloys under other conditions. The authors were led by this test to the view that the alloys described in the Ninth Report would resist corrosion better than pure aluminium, but although some of these alloys had undoubtedly remarkable properties in this respect, he could not say that several years' experience of them on a large commercial scale enabled him to endorse the authors' view. It seemed reasonable to assume that the pure zinc they used would render their alloys more resistant to corrosion than those made industrially, and it might be well to point out that this remarkably pure metal was a commercial article readily obtainable. Judging from analogy, the annealed test-pieces would certainly behave better than those which were unannealed; but could not the authors use their unique facilities to submit these alloys to a thorough investigation with regard to corrosion? By so doing they would certainly render excellent service, and would probably contribute in no small measure to the wider introduction of these alloys which they must desire. For those which were to be used for automobile castings, corrosion was not to be feared, because these castings were always coated with oil which protected them absolutely. But if his (Dr. Seligman's) suggestion that these alloys could be used for panelling found favour, they must be free from that particular form of corrosion which consisted in sloughing the paint used to decorate the body-work. This could be easily tested by the authors.

Another use to which these alloys might very profitably be put, in the event (he must, he feared, say the unlikely event) of their chemical resistance being sufficient, was for culinary ware. In England a large number of cooking vessels were made of cast aluminium, which found favour on shipboard, in trains and hotels, owing to their power to withstand rough usage. Considerable, difficulty was experienced in casting pure aluminium for this purpose and manufacturers would doubtless promptly avail themselves of any alloy which would help them over this difficulty. For this purpose the corrosion tests necessary would be confined to determining whether pitting, foliation, etc., took place, and to an estimation of the ingredients which passed into solution in the various liquids in question. Such tests could very easily be carried out under the

(Dr. Richard Seligman.)

supervision of the authors, and it would be easy to specify quite a number of other uses to which the alloys could be put, if information were available as to their chemical as well as their mechanical behaviour. The writer earnestly hoped that the authors would see their way to falling in with this suggestion, which would, he believed, increase immensely the debt under which they and the Alloys Research Committee had already placed the aluminium industry.

Mr. LEONARD SUMNER wrote that he thought Dr. Rosenhain and Mr. Archbutt had evidently done a vast amount of valuable work, which was, however, mainly preliminary to the discovery of what might prove to be commercially satisfactory ternary alloys. The authors' conclusions were in several respects different to the unusually held beliefs of those who had had experience in the manufacture of these alloys. The authors in their investigations had used Brunner Mond's special spelter containing 99·98 per cent. of zinc. This spelter was only produced on a limited scale, and was thus difficult to obtain. For practical purposes it would have been desirable if side by side with their investigations, using Brunner Mond's spelter, the authors had tested alloys made with ordinary commercial spelter, and to have seen if there was any difference in the results obtained. It was well known that Dr. Rosenhain held the belief that the impurities in spelter lent to corrosion, but the writer thought that this belief was still subject to proof. Another point which seemed greatly to impair the practical use of these alloys (and this applied also to the ternary alloy named in the Appendix) was their extreme sensitiveness to hot-rolling. An alloy which broke up into powder if slightly too hot could not be of much value in its rolled state, owing to the practical impossibility of manufacturing on a commercial scale.

Mr. C. HUMPHREY WINGFIELD thought the usefulness of the property the authors had called "specific tenacity" would be extended if they would define its meaning in as many ways as possible. For example :—

(1) It was stated on pages 329 and 360 to be the breaking load in tons of a bar whose weight was 1 lb. per inch length.

(2) It was also the breaking weight of a section having an area (in square inches) equal to the number of cubic inches in one pound of the material.

(3) The specific tenacity × 2,240 = the length in inches of a vertical bar of uniform section which would just break by the tension produced by its own weight when suspended from its upper end.

With a given specific tenacity and factor of safety, the sectional area of a member of a structure in tension would vary as the cubic inches per lb. of the material used. In structures where resistance to wind was of importance, assuming this to vary as the projected area, it followed that the load from wind pressure on such a structure as the light wire bracing of an aeroplane would vary as $\sqrt{\text{cubic inches per lb.}}$ The stress therefore due to wind, if chiefly tensional, would vary as $\frac{\sqrt{\text{cubic inches per lb.}}}{\text{cubic inches per lb.}}$, that is, inversely as the $\sqrt{\text{cubic inches per lb.}}$

An interesting feature of the Report was the number of instances in which reversals of physical relations took place at definite percentages of zinc. Thus:—

(1) The relative density of sand- and chill-castings reversed at about 50 per cent. zinc.

(2) Their relative compressive yield-stress reversed at about 40 per cent. zinc.

(3) The relative specific tenacity of $1\frac{1}{4}$-inch and $\frac{7}{8}$-inch bars (both rolled) reversed at about 15 per cent. zinc.

(4) The tints of different parts of prepared microscopic sections changed places at about 26 per cent. zinc or a little over that proportion.*

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* Possibly this was only a coincidence due to a change in the direction of the light. Fig. 3 (page 652) of *Engineering*, vol. xciii, was a pair of views of the same section showing the same reversal. It was supplied by Dr. Rosenhain, and Sir James A. Ewing explained that in this instance the appearance depended on which of two directions the light came from.

(Mr. C. Humphrey Wingfield.)

He was not clear whether any of the hot-rolled material was prepared from chill-castings. The sheets (page 371) were sand-cast. On page 344 it was stated that rolling-billets (of dimensions not stated) were cast, but whether in sand- or chill-moulds did not appear.

He gathered from page 396 that a 25 per cent. alloy had received as much punishment as it would stand without injury when reduced from the size of the original billet to a diameter of $1\frac{1}{4}$ inch. Further rolling reduced its ductility. In drawing comparisons between the strengths of $1\frac{1}{4}$-inch and $\frac{7}{8}$-inch bars, as on page 325 for instance, it seemed desirable to give the fraction of the original billet's diameter to which they had been reduced, as it was most unlikely that any important quality attached to a particular dimension irrespective of the amount of work done to the material in attaining it.

The resistance to alternate bending was said to be "strictly" proportional to the zinc-content (page 335). Fig. 10 (page 348) showed that it was more nearly proportional to the zinc-content less 9 per cent. when the drop of the tup was 0·71 inch, and less 11 per cent. when the drop was 1 inch.

Generalizations, if not carried too far, were always interesting and often valuable, and he thought this was the case with the authors' conclusions (pages 335, 336, 434, 435, 436) as to the qualities indicated by each of the three dynamic tests considered. He welcomed them as a useful guide in interpreting results of such tests.

Some of the qualities claimed for these binary alloys were likely to make them useful in every-day life. For instance:—

(1) Freedom from tarnish (page 336).

(2) Remarkable "ring" (page 346).

(3) Great elasticity (pages 417–9).

Of these (1) and (2) suggested their use for bells and gongs; (3) suggested the possibility of their being fit for the manufacture of non-magnetic balance springs for watches.* The low value of E

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* Their fitness for this depended on the absence of mechanical hysteresis (*Engineering*, vol. xciii. p. 694, Fig. 5), and on whether their elastic qualities persisted without change after a long period of repeated applications of stress.

(page 420) would cause springs to be too bulky for power-storage purposes however.

The effect of ageing in increasing the tenacity was remarkable, and pointed to internal stresses which were relieved as time went on, enabling all portions of a given section to take a more uniform share of the resistance than was possible before the crystals had "settled down."

What was meant by "hardness"? It was evident from Fig. 106 (page 438) that the two tests did not measure the same quality. Which was to be preferred? As the yield-point in compression was always higher than in tension (page 428), it was safe to design members of a structure subject to bending on the basis of tensile strength alone.

Would it be too much trouble to explain how complete equilibrium (*see* bottom of page 366) would be indicated on a diagram such as Fig. 1 (page 338)? Would it be shown by three lines meeting in one point, as at G, or how? Was he right in understanding that at higher temperatures than that represented by C G H the compound Al_2Zn_3 decomposed? Not only individuals but the whole profession were under a deep debt of gratitude to those who, like the authors of this Report, brought exceptional ability to bear on difficult researches like these, and who gave the results with such remarkable clearness.

THE AUTHORS wrote, in reply to the written communications, that they were particularly gratified with the kind remarks of Sir Robert Hadfield (page 497)—appreciation, coming from such an experienced worker in the scientific study of alloys, was particularly welcome. As regards the suggestion of testing the alloys after water-quenching, the authors would point to the equilibrium diagram, from which it would appear that all the most interesting alloys were simple homogeneous solid solutions showing no critical changes below the solidus line, and for that reason no special results were to be anticipated from water-quenching. A few experiments (not described in the Report) confirmed this view, and the matter was not further pursued.

(The Authors.)

Mr. H. J. Bubb's remarks (page 496) furnished a striking confirmation from practical experience of the correctness of the authors' views as to the deleterious effects in these alloys of impurities derived from zinc, and the absence of deterioration with lapse of time in pure alloys.

With regard to Mr. Lantsberry's ingenious suggestion (page 498) that the effect of work in the case of the higher zinc alloys may have been less additive than in the lower ones owing to specially prolonged or careful annealing of the more difficult alloys, the authors could only remark that all the 1¼-inch bars were treated alike. The difficulty in rolling the harder alloys occurred at the beginning of the process when the billets were first broken down; once this stage was passed no special trouble was experienced and no special annealing was applied. In all cases the 1¼-inch bars were heated sufficiently long before further rolling to anneal them fully, so that, apart from those effects of work which persisted after all annealing, the work was not really "additive" in any of the hot-rolled alloys.

The authors were much interested in Dr. Seligman's remarks (page 504), but they thought that he took too one-sided a view of the possibilities of such alloys and of the scope of the data which were required concerning them. The possibilities for the use of the higher zinc alloys in the form of wrought material, as suggested by the results contained in the Report, had appeared to the authors to be far more promising and of far wider scope than their use as castings for the automobile industry. Professor Huntington had deprecated even tensile tests of sand-castings, and now Dr. Seligman asked for dynamic tests. It would, of course, be quite easy to make such tests, but very difficult to interpret the results obtained, since—so far as they were aware—no shock tests on cast alloys, and especially light alloys, had yet been published. It was, further, a doubtful point whether shock tests on such relatively brittle material could give satisfactory indications at all, and in any case it was open to question whether the usage received by automobile castings was really analogous to any test yet devised. They could not help thinking that the evil repute of castings of the aluminium-zinc alloys under such conditions was not at all due to any inherent weakness of the alloys as such, but to the fact that the alloys which had been tried in practice were made of impure material and were therefore comparatively weak to begin with and liable to deterioration with age. Mr. Bubb's remarks bore out this view.

With regard to Dr. Seligman's remarks on corrosion tests, the authors quite agreed that corrosion was best detected by careful examination of the specimens, but it was difficult to see how such ocular examination could be converted into a quantitative test for comparative purposes. For that reason the tensile test-pieces had been chosen for corrosion tests, since tensile stress would find out either general or local corrosion even more unfailingly than an experienced eye.

Mr. Sumner's remark (page 508) that "Brunner Mond's special spelter containing 99·98 per cent. of zinc . . . . was only produced on a limited scale, and was thus difficult to obtain," might be compared with Dr. Seligman's statement "that this remarkably pure metal was a commercial article readily obtainable." Recent metallurgical history had shown that almost any material, even though it had been regarded as rare and expensive, soon became available in large quantities and at a reasonable price once a demand for it arose. As regards pure zinc, refining methods would be rapidly developed once there was a real demand for a metal of high purity As regards the view that impure zinc tended towards corrosion, experiments had been quoted by the authors which definitely substantiated this opinion so far as aluminium-zinc alloys were concerned.

The authors also could not accept Mr. Sumner's view that the sensitiveness of the alloys to hot-rolling constituted a bar to their commercial production. Many metallurgical operations could be quoted which were carried out successfully on the large scale, in which temperature control quite as close as that demanded by these alloys was habitually employed. The authors felt sure that no enterprising manufacturer would be deterred by this difficulty from undertaking the production of these alloys, once a large and

(The Authors.)

reasonably profitable market was assured for them. If metallurgical manufacturers demanded that all new materials should be capable of being handled in the same way as the other alloys to which they were accustomed, that would constitute a very serious obstacle to the development of new and improved materials, and would in fact result in the transfer of that development to countries where technical difficulties were more boldly faced. The fact that "Duralumin" had been developed abroad was already evidence that English manufacturers had too long neglected the subject of light alloys.

Mr. Wingfield's exposition of the various ways of expressing the meaning of "specific tenacity" (page 508) was of much interest to the authors; they might add the strictly scientific definition that the "dimensions" of this quantity are L^2/T^2, or "square feet per second per second." The authors were also indebted to Mr. Wingfield for summarizing the various reversals of properties at concentrations of zinc lying mostly between 15 and 20 per cent. of zinc. These reversals were mentioned in most cases in the text of the Report; the change in the appearance of the etched constituents was, however, a real one, since all the photomicrographs had been taken under the same (normal) lighting.

As regards the method of preparation of the rolled bars, reference was made in the Report to the billet-moulds described in the Eighth and Ninth Reports—these moulds were of iron, the billets being in every case 3 inches in diameter. In that sense, therefore, the rolled bars were prepared from chill-castings, but it was probable that after heating and rolling, the distinction between a bar derived from a chill-cast or from a sand-cast billet would be very slight. The general fact that all rolled material was derived from 3-inch billets was indicated in the Report by the references just mentioned, and this met Mr. Wingfield's suggestion. The authors, of course, agreed that the properties of rolled bars would depend upon the amount of work done on them or reduction produced, and on their absolute diameter only in so far as that governed the rate at which the bar cooled down while passing through the rolls.

The definition of "hardness" was too complex a question to be discussed here; the Brinell and Scleroscope figures were given side by side, and they must be taken merely as empirical results measuring certain combinations of physical properties which more or less accurately represented "hardness." The authors rather looked upon the Brinell figures as the standard, and gave the Scleroscope figures for comparison and on account of the ease with which such figures could be obtained.

The question of the representation of complete equilibrium on such a diagram as Fig. 1 (page 338) also raised matters which could not be gone into here. There were several ways in which imaginary lines could be drawn to "complete" that diagram, and for an example the author would refer to the discussion on their Paper before the Institute of Metals at Newcastle-on-Tyne last September. The difficulty was that their experimental evidence disproved the existence of some of these lines and quite failed to prove the existence of others. While further research might clear up these discrepancies, in the present state of affairs the authors did not care to advance any speculations on the question.

In conclusion, the authors desired to express their thanks to the gentlemen who had gone to the trouble of contributing to the discussion; many of those contributions contained very valuable suggestions for further and future work. Even beyond the present reply, those suggestions would receive most careful consideration from the authors in conducting their further researches, and very probably some of those suggestions would be found materialized in the next Report. On the other hand, it must be borne in mind that some limit must be set both to the number and variety of experiments undertaken and to the lines of enquiry to be followed —the authors were bound to make a somewhat narrow selection from all the inviting lines of research which opened up before them.

ON THE MEASUREMENT OF THE AIR-SUPPLY TO INTERNAL-COMBUSTION ENGINES, BY MEANS OF A THROTTLE-PLATE.

BY PROFESSOR WILLIAM WATSON, D.Sc., F.R.S.,
AND HERBERT SCHOFIELD, A.R.C.S., B.Sc.,
Associate Member, OF LONDON.

[*Selected for Publication.*]

The throttle-plate method of measuring a flow of air, in which the volume of air which passes is deduced from the drop of pressure on two sides of a circular orifice in a thin partition, has been studied by several observers, notably A. O. Muller,* R. J. Durley,† W. E. Dalby, ‡ and Weisbach. §

In all the above determinations, either the pressure difference was quite steady during each observation, or no account was taken of any variation which occurred. In the case of the experiments by Muller and Durley, the air passed from a box into the open air, while when this method is to be employed to measure the air-supply to an internal-combustion engine, the flow takes place from the open air to a box, and unless a box of quite unwieldy dimensions is employed, the pressure inside the box varies owing to the cyclical variation of the suction of the engine during each stroke.

Durley made a few experiments on the effect of varying the size of the box, but these were not extensive, and the effect to be expected is likely to be different when the air streams into the box from what it will be when the air streams out. Hence the series of experiments below have been undertaken, in which the air streams into a box, and the effect of a cyclical * variation of the pressure in the box has been investigated for different sizes of box.

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* *Zeitschrift des Vereines deutscher Ingenieure*, 22 February 1908.

† Trans. American Society of Mech. Engineers, 1906, vol. 27.

‡ *Engineering*, 9 September 1910, page 380.

§ *Der Civilingenieur*, 1859, vol. 5, page 546.

When a difference of pressure equal to p centimetres of water exists on opposite sides of a circular orifice of area F square centimetres, the volume V in cubic centimetres of air which will pass in t seconds is given by:—

$$V = a\, t\, F \sqrt{\frac{2\, g\, p}{\rho}}$$

where ρ is the density of the air in grams per cubic centimetre, and a is a coefficient which varies with the pressure difference p, the area F, and also with the size of box used. The present series of experiments has for its object the determination of a under various conditions.

The accuracy aimed at was about 1 in 500, and the attempt was made to measure the different quantities involved to within this limit. This accuracy seems to have been approached, for the mean difference between the two sets of experiments given in Table 2 (page 533) amounts to 1 in 300. The mean difference from the mean thus only amounts to 1 in 600.

Description of the Apparatus and Method of Experiment.—The general arrangement of the apparatus is shown in plan in Fig. 1. Air was drawn into a large gas-holder P through boxes A, D, E, and M, by means of a Bryan Donkin rotary gas suction-pump G. This pump was driven by an electric motor, and the speed was capable of a very fine adjustment by means of resistances placed in the supply circuit. Current was taken from a set of accumulators, used for no other purpose, so that there should be no fluctuation in the voltage of supply during the time of running a test. By

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* By cyclical variation is to be understood the variation occurring during each stroke of the pump or engine.

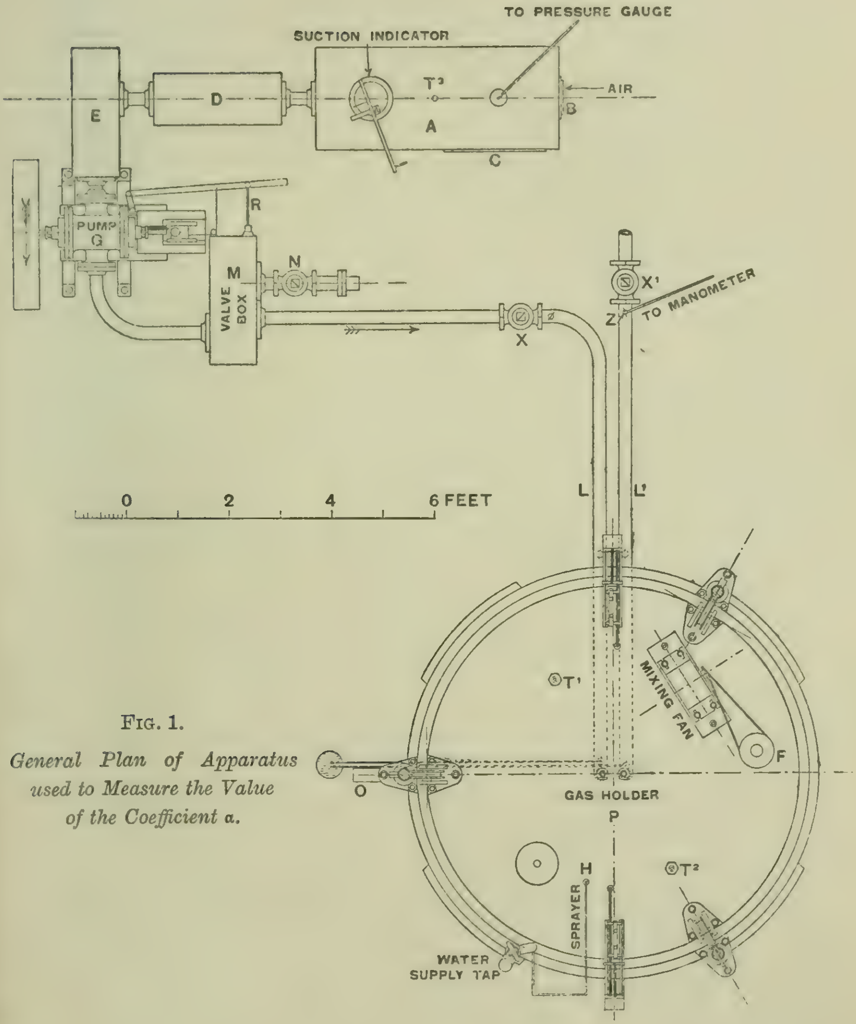


Fig. 1.

General Plan of Apparatus used to Measure the Value of the Coefficient α.

this method the speed could be so adjusted as to maintain the mean-pressure difference constant to within $\frac{1}{100}$ of an inch of water. The air was drawn through an orifice in a thin metal plate at B into the box A. Its temperature was measured by means of the thermometer T^3, and the hygrometric state was obtained from a wet and dry bulb hygrometer placed near to the orifice, but not so close as to be actually in the stream lines. From the box A, in one side of which was a diaphragm about 18 inches square of thin sheet indiarubber, the air passed through a box D containing a series of baffle-plates of perforated zinc, arranged in sections of about twenty plates.

The effect of these baffle-plates and the large indiarubber diaphragm was to damp out most of the periodic variation of pressure due to the variable suction of the pump, and to give a fairly steady flow through the box A. E was a box placed between the pump and the box D, and acted as a reservoir from which the pump could take its supply. After passing through the pump the air traversed a valve-box M, where it could either be sent along a pipe leading to the gas-holder, or blown out into the atmosphere through the pipe N. The change from one condition to the other was made by pulling out the rod R, which worked a slide running along one side of the box. This rod was fixed to a lever connected to a revolution-counter, so that as the air current was switched over into the gas-holder circuit, the counter was automatically put into gear with the pump-spindle, thereby giving the number of pump strokes during the test.

The two pipes L and L^1, closed by the stop-cocks X and X^1, were connected to two stand-pipes inside the gas-holder, and could be used for the supply and discharge of the air respectively. In the enlarged end of the pipe N were placed several diaphragms of fine gauze, which were adjusted so that the resistance to the flow of the air was the same as that of the pipes leading to the gas-holder, and thus on changing the valve, no change in the speed of the pump, and hence in the pressure in the box A, took place.

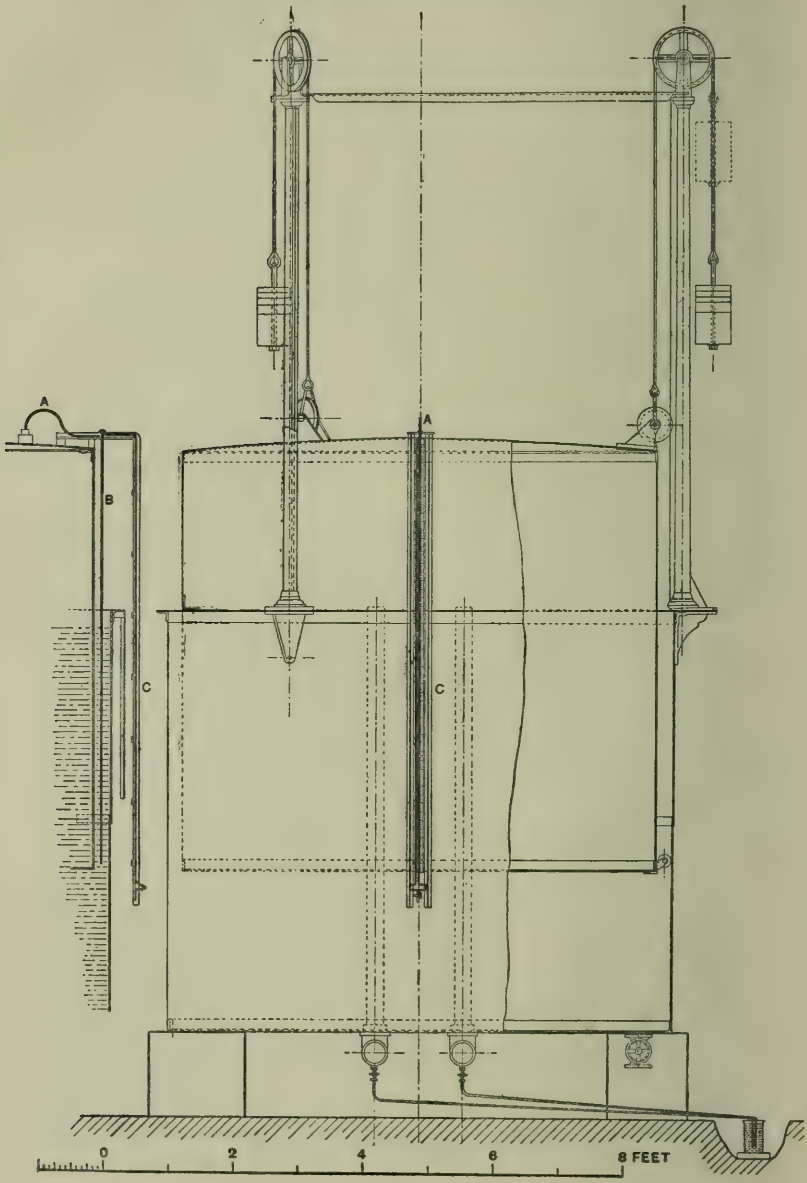
The Gas-holder.—This was of the inverted-bell type of about 250 cubic feet capacity, of which the dimensions are given on Fig. 2 (page 522). It was water-sealed, and the height of the water level within the bell was measured by means of two water-gauges, carried on opposite sides of the bell. Each of these consisted of a glass U-tube C, supported by a bracket attached to the top of the bell, and passing down clear of the outside of the tank.

One end of this U-tube was connected by the pipe A, with the interior of the bell, and the other end was connected to a vertical pipe B, which passed down between the bell and the tank and reached to the bottom of the bell. The whole of the tube B, together with the whole of one of the branches of the U and the lower part of the other branch, was filled with water, while the upper part of this branch was filled with air at the pressure existing in the bell. Thus the level of the surface of the water in the U-gauge C was the same as that of the surface of the water inside the bell. This level was read by means of a brass scale graduated in millimetres and fixed alongside one of the limbs of the U-tube; the position of the water meniscus on this scale was read by a lens.

The weight of the bell was largely counterpoised by three weights, which were secured to it by flexible steel-wire ropes running over pulleys carried by three standards fixed to the tank. All these pulleys were mounted on ball-bearings, and the guide-pulleys running up the sides of the standards were also fitted in this way to secure a regular motion as the bell was driven upwards by the incoming air. The difference of pressure between the bell rising and falling only amounted to 7 mm. (0·27 in.) of water.

To promote circulation of the air contained within the bell a small electric motor was fitted to the top of the bell, which drove a fan working on a vertical shaft passing through an air-tight stuffing-box, the weight of the motor being balanced by weights on the opposite side of the bell. A water spray was also fitted through the crown of the bell, by which means the equalization of the temperature of the air was assisted, and at the same time complete saturation with water vapour was secured. It was found

FIG. 2.—*The Gas-holder.*



by direct experiment that about fifteen minutes was sufficient for the incoming air to reach a steady temperature and hygrometric state, and this interval was allowed in each experiment, before any readings of volume were made.

The temperature of the air inside the bell was given by two mercury thermometers T^1 and T^2, Fig. 1 (page 519), which were divided into tenths of a degree Centigrade, and had been previously calibrated over the whole range of temperature used. The pressure difference between the interior and exterior of the bell was read off directly on a water manometer attached to the return pipe at the point Z.

For the calibration of the bell, twelve equidistant vertical lines were marked round the circumference of the inside, and then by means of two scales, divided in millimetres, sliding one over the other, the diameter in six directions was obtained for every foot of depth. Thus the mean diameter, and consequently the area, could be obtained for a series of sections of the bell.

The volume of the curved top of the bell was determined in the following manner. The whole of the air contained in the bell and connecting-pipes down to the valves X and X^1 was removed by means of a water-pump. Incidentally small leaks in the connections were at once discovered owing to the continuous stream of small air-bubbles drawn off by the pump. After considerable trouble all these leaks were eliminated. A needle-point was then adjusted to the surface of the water in the outside tank and the water was drawn off, air being admitted to the bell until the surface of the water inside was just below the top of the cylindrical portion. The level of the water outside was kept constant at the level of the needle. The volume of the water drawn off was directly measured, and this volume was equal to that of the upper part of the bell down to a point which was noted on the scales of the gauges. The water contained in the stand-pipes was also drawn off and measured, and an allowance was made for the volume occupied by the amount of the wall of the pipes which projected into the bell.

The volume of the bell and stand-pipes, etc., for different readings of the gauges was then plotted on a curve, so that, having the reading on the gauges, the volume of air contained in the bell could be immediately read off.

Air-boxes.—These were made of 3-inch by 2-inch frames and panelled with "compo-boarding," the panels being set in a paste of zinc-white and gold size to ensure the joints being air-tight. It was not assumed that the joints made in this way remained perfectly air-tight, as tests for leaks were made in a manner to be described later.

Three boxes were used in the tests, the dimensions being respectively :—

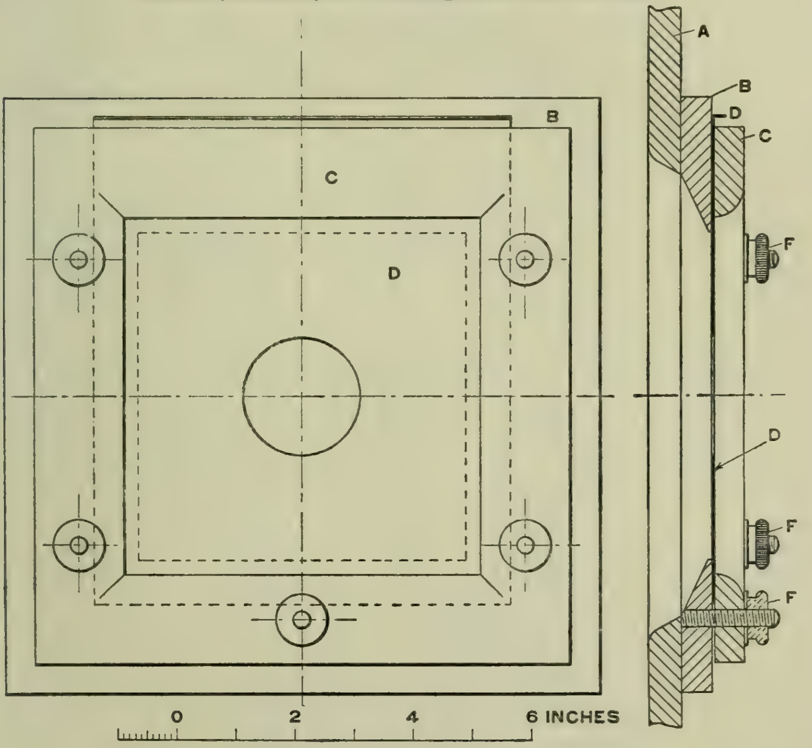
(1) 57 inches by 25 inches by 25 inches or 17·36 cubic feet capacity.
(2) 38 inches by 17 inches by 17 inches or 4·66 cubic feet capacity.
(3) 28 inches by 13 inches by 13 inches or 1·53 cubic feet capacity.

Diaphragms.—These were cut from tin-plate of thickness 0·4 mm. or 27 S.W.G., and the holes turned out in the lathe to make sure that the orifice was as round as possible. Great care was taken to see that the holes had a perfectly sharp edge. This is a most important detail, as rounding of the edges will make an appreciable difference in the value of the coefficient. It was found to be a good method to solder cover-plates on each side of the tin-plate, before boring out the orifices, and then after the hole had been cut remove them by melting off. This seems to give a good square sectioned hole in the central plate. After being turned out each hole was carefully measured by a travelling microscope across two diameters at right angles, and the mean value taken for calculating the area.

A little trouble was experienced in making an air-tight joint which would permit of the diaphragms being easily taken in and out of position on the box, but eventually the method shown in Fig. 3 was adopted as giving the best result and proving very simple to use. A square wood frame B is screwed to the end of the box A. There is a hole about 6 inches square in the frame, and the inner edges are chamfered back to prevent an interference with the entering air. The front of the frame is covered with soft chamois leather which is turned back through the square hole and fastened down on the inside. Another frame C, held on to the former by five milled headed nuts F, serves to hold the diaphragm D in position, and presses it tightly against the soft leather.

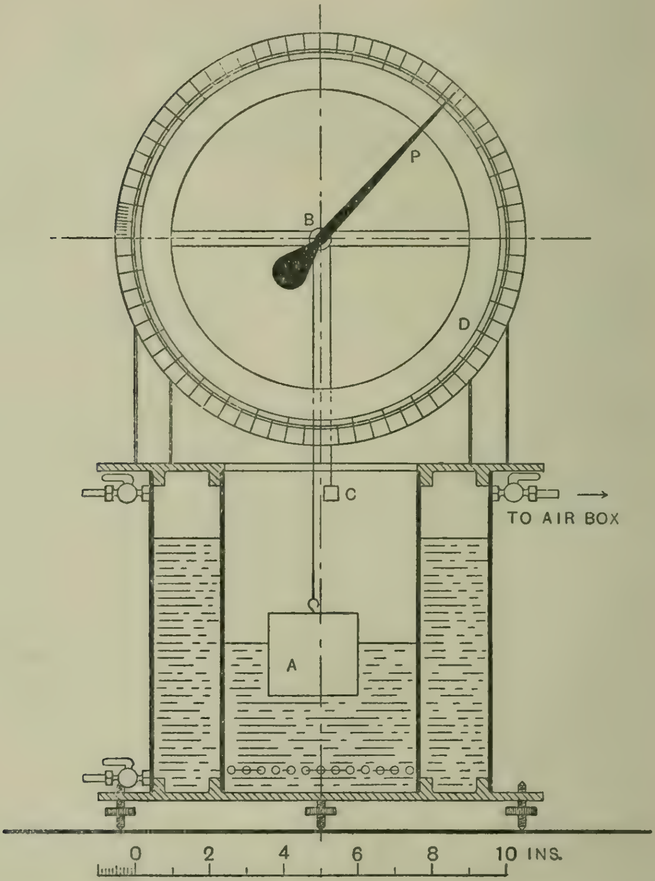
FIG. 3.

Method of attaching the Throttle-plates to the Air-Boxes.



Measurement of Pressure Difference.—In order to measure the mean difference of pressure between the two sides of the throttle-plate it was necessary to have an instrument reading to about 0·001 of an inch of water, and such that the readings could be

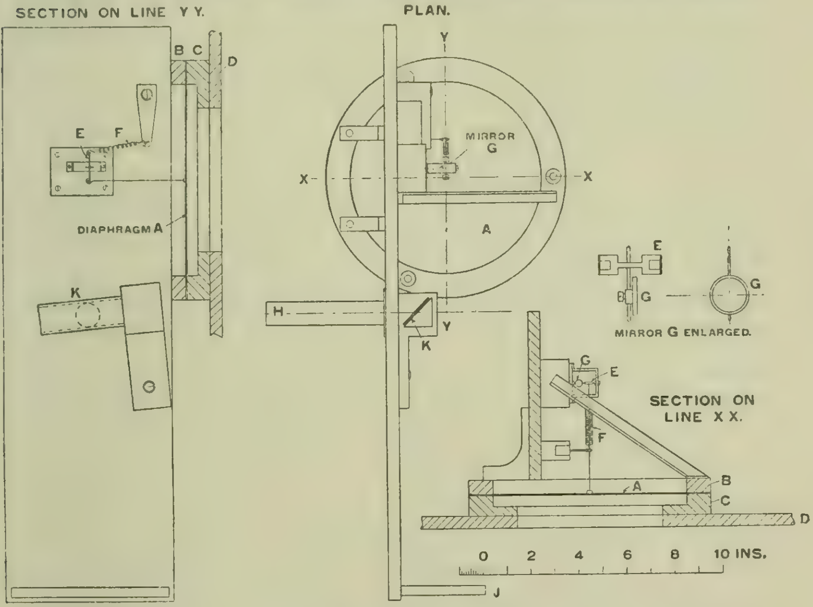
FIG. 4.—*Gauge for measuring the Mean Difference of Pressure between the two sides of the Throttle-plate.*



made with great rapidity. For this purpose a modified form of "King" gauge was constructed. The details of this are given in Fig. 4. A float A is suspended by a fine silk fibre which is coiled round a drum B, on the surface of which there is a spiral groove, the other end of the fibre being attached to a counterpoise C. The drum and pointer are secured to a fine spindle mounted on jewelled bearings in such a way that the pointer can move over the whole circumference of the dial D, which is graduated to read in hundredths of an inch of water (one division of the scale is about $\frac{1}{10}$ of an inch). The readings of this instrument were standardized by direct comparison with a Threlfall micrometer gauge* immediately after each test.

Fig. 5.

Optical Indicator used to measure the Variation of Pressure in the Air-Box.



To measure the variation in pressure in the box A, Fig 1 (page 519), due to the suction, a thin sheet-iron diaphragm A, Fig. 5, was clamped between two wooden rings B and C, the lower ring being screwed to the top of the box D. A light wire-link connects the centre of the diaphragm to a small pivoted lever E, which is also shown on a larger scale. A spiral spring F keeps the link in tension, the link and spring being attached to the lever by hooks which rest on knife edges. A concave mirror G of about 19 centimetres focal length is carried by the lever and forms on a matt surface celluloid scale at J an image of a cross wire at H, the light being reflected into the mirror by a fixed mirror K placed at an angle of 45°. A Nernst lamp was used to illuminate the cross wire, so that the scale could be read without darkening the room. The period of the diaphragm was sufficiently small to allow of its following the pressure changes in the box.

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* Threlfall: Proceedings, Institution of Mechanical Engineers, 1904, Part 1, page 251.

Method of making the Trials.—The pump was started up and allowed to run for some time, so that conditions became steady. Meanwhile the air was blown out through a resistance in the pipe N, Fig. 1 (page 519), which was adjusted so that it was equal to the resistance offered to the air by the stand-pipes in the gas-holder. In this way, when the valve R was switched over, there was no change in the reading of the pressure instruments caused by a variation in the speed of the pump. By the use of this device it was possible to arrange to run a trial at any desired pressure difference across the orifice, and to make all the instruments steady before switching over the air-current on to the gas-holder. During the time that the gas-holder was being filled, readings were taken every fifteen seconds of the temperature of the incoming air and the pressure difference across the orifice. The hygrometric state of the air and the height of the barometer were observed and the time was taken on a chronometer. After about twenty minutes, when the air inside the bell had reached a steady temperature and become saturated with moisture, the readings of the pressure inside the bell were taken, and the two gauges and two thermometers were read simultaneously by observers on each side of the gas-holder. The readings were reduced in the following manner :—

Let T = the mean temperature in degrees Centigrade of the air in the gas-holder.

,, H = the vapour pressure of water at T° C. in millimetres of mercury.

,, q = the difference in pressure between the inside and outside of the gas-holder in millimetres of mercury.

,, B = the height of the barometer in millimetres of mercury.

,, T_1 = the temperature of the air passing through the orifice.

,, h = the vapour pressure of water vapour contained in the air passing through the orifice, measured in millimetres of mercury.

,, V = the volume of air which passes through the orifice during the experiment, measured under the condition in which it existed in the gas-holder.

,, v = volume of the same air under the condition in which it passed through the orifice.

,, F = area of orifice in square centimetres.

,, p = difference of pressure on the two sides of the orifice in centimetres of water.

,, t = the time in seconds.

,, ρ = the density of the air in grams per cubic centimetre, at a pressure of $B - \frac{3}{8}h$ and at a temperature T_1° C.

,, α = the coefficient of contraction.

Then reducing the volume V to the conditions as to pressure, temperature and hygrometric state which held during the passage of the air through the orifice we get:—

$$v = V\left(1 - \frac{H - h}{B + g}\right)\left(\frac{B + q}{B}\right)(1 + 0{\cdot}00367\,(T_1 - T)).$$

$$\therefore \quad v = \frac{V}{B}\{B + q - H + h\}\{1 + 0{\cdot}00367\,(T_1 - T)\}.$$

This will give the volume of air actually measured, and if the pressure difference p is steady,

$$v = \alpha F t \sqrt{\frac{2gp}{\rho}}.$$

$$\therefore \qquad \alpha = \frac{v}{F t \sqrt{\frac{2gp}{\rho}}}.$$

Method of Testing for Leaks.—The air-boxes were made as nearly air-tight as possible, and then pumped up to some definite pressure as registered on a manometer attached to each box. The time was taken for the pressure to fall to half its initial value. From this the leak per second could be calculated, since the cubical capacity of the box was known. The places where the leak occurred were located by filling the boxes with coal gas and finding the points at which the issuing gas could be ignited. These were stopped by Chatterton cement and the rate of leak determined again. In this way the process was repeated until any leak obtained was so small that it could not affect the percentage accuracy aimed at in the experiments. The whole of the apparatus was treated in this way, using higher pressures than any which it had to stand during the actual tests.

The stoppage of leaks in all parts of the apparatus proved to be a most difficult task, and it was only after considerable time had been spent that this was finally accomplished. The boxes now used for the application of this method to engines are made of wood covered outside with zinc, all the joints being soldered, so that once the leaks are stopped no further difficulty arises.

Experiments with no Cyclical Variation in the Pressure Difference, Tests A.—The large box of 17·36 cubic feet capacity was used, and the arrangement of the apparatus was as shown in Fig. 1 (page 519). By means of the resistance-box D and the rubber diaphragm in the side of box A, the variations from the mean pressure as given by the optical indicator shown in Fig. 5 (page 527) were damped down to an inappreciable value (0·074 inch of water at a mean pressure difference of 1 inch).

The orifices used ranged from ½ inch diameter up to 2 inches diameter, and at each size the pressures were varied from ½ inch of water to 2 inches. Two series of observations are given in the Tables; these correspond to measurements made on different days.

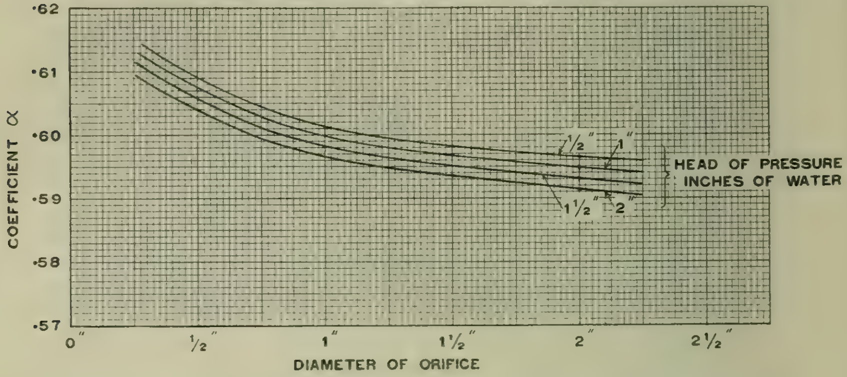
The observations are given in Table 1, and the values of the coefficient a in each case are collected together in Table 2 (page 533). These are plotted in Fig. 7 (page 532), where the value of a is represented by the ordinates and pressure differences by the abscissæ.

TABLE 1.

Data Observed during each Experiment with the Large Box.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Time of Experiment.	Temperature of Air.	Barometer (corrected).	Hygrometric State.	ρ = Density of Air. Grams per cm^3.	Value of the Coefficient a.
In.		Secs.	°C.	Mm.	Mm.	0·00	
2	2·059	160	16·43	773·7	11·33	1235	0·591
,,	2·060	160	16·04	773·7	11·08	1237	0·591
,,	1·519	180	15·77	761·7	9·66	1220	0·596
,,	1·526	180	18·18	764·0	12·05	1212	0·595
,,	1·010	230	20·12	757·6	12·60	1194	0·596
,,	1·004	215	14·85	762·1	9·97	1222	0·595
,,	0·531	300	17·38	761·7	10·44	1212	0·595
,,	0·561	300	17·60	764·0	11·84	1215	0·596
1·5	2·122	270	18·23	757·8	12·96	1201	0·596
,,	2·123	290	15·12	763·0	10·64	1224	0·595
,,	1·506	320	16·88	758·5	11·65	1207	0·595
,,	1·515	330	15·93	766·2	10·70	1224	0·595
,,	1·023	390	19·91	757·6	12·36	1194	0·595
,,	1·051	390	14·67	762·1	9·38	1224	0·598
,,	0·511	570	16·90	761·7	10·24	1214	0·596
,,	0·522	570	16·37	766·2	11·18	1222	0·600
1	2·115	300	17·87	757·8	12·90	1202	0·599
,,	2·080	300	16·51	763·0	11·04	1217	0·597
,,	1·508	360	16·33	758·1	11·37	1210	0·599
,,	1·528	360	14·83	762·0	9·63	1223	0·597
,,	1·010	450	20·31	757·6	12·51	1193	0·597
,,	0·995	420	14·86	762·1	9·83	1222	0·599
,,	0·510	630	17·75	761·7	10·74	1211	0·596
,,	0·526	600	16·53	762·0	10·36	1216	0·599
0·5	2·044	630	18·06	757·8	13·56	1202	0·607
,,	2·001	630	16·49	767·9	7·73	1227	0·603
,,	1·488	720	16·13	758·1	11·22	1210	0·608
,,	1·507	720	19·20	766·2	12·45	1211	0·605
,,	1·011	900	20·27	757·6	12·42	1193	0·608
,,	1·001	900	17·22	766·2	11·76	1218	0·608
,,	0·511	1200	16·70	753·1	11·49	1200	0·610
,,	0·543	1200	17·38	757·8	12·88	1204	0·607

FIG. 6.—*Curves showing the Change in the Value of the Coefficient* α *with diameter of Orifice, for Different Values of the Pressure Difference.*



FIGS. 7, 8, and 9.—*Curves showing Change in the Value of the Coefficient* α *with Pressure Difference, for Different Orifices.*

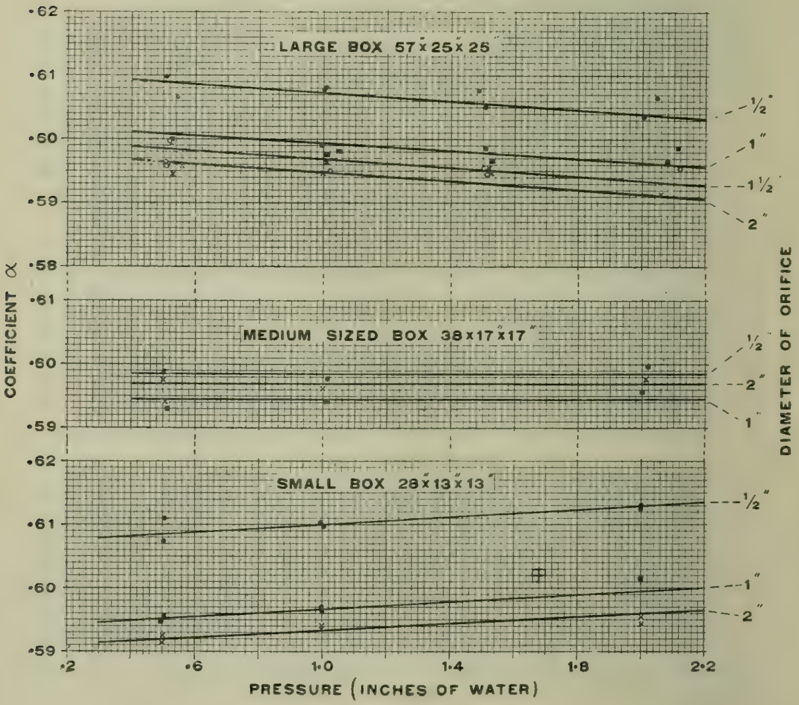


TABLE 2.

Large Box with Steady Pressure.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Co-efficient a.	Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Co-efficient a.
In.			In.		
2	2·059	0·591	1	2·115	0·599
,,	2·060	0·591	,,	2·080	0·597
,,	1·519	0·596	,,	1·508	0 599
,,	1·526	0·595	,,	1·528	0·597
,,	1·010	0·596	,,	1·010	0·597
,,	1·004	0·595	,,	0·995	0·599
,,	0·531	0·595	,,	0·510	0·596
,,	0·561	0·596	,,	0·526	0·599
1·5	2·122	0·596	0·5	2·044	0·607
,,	2·123	0·595	,,	2·001	0·603
,,	1·506	0·595	,,	1·488	0·608
,,	1·515	0·595	,,	1·507	0·605
,,	1·023	0·595	,,	1·011	0·608
,,	1·051	0·598	,,	1·001	0·608
,,	0·511	0·596	,,	0·511	0·610
,,	0·522	0·600	,,	0·543	0·607

It will be observed that with the large box the value of the coefficient a does not change to any very great extent either with pressure difference or size of orifice within the limits of the experiments. It is, however, quite clear that a increases slightly with a decrease of pressure difference and with decrease in size of orifice.

To obtain a better idea of the rate of change, the values of a have been plotted in Fig. 7 on such a large scale as to make the change apparent. Owing to the fact that the scale thus adopted is more open than the accuracy of the observations will justify, the points appear rather irregular.

It will be obvious that the parallel straight lines drawn represent the variation of a as nearly as the accuracy of the observations warrant. In order to assist in obtaining the values of a for intermediate diameters of orifice, the curves showing the change in the value of a with diameter of orifice for different pressure differences are plotted in Fig. 6.

Tests B and C.—A similar series of tests /were/ made with the was other two boxes. In each case these boxes were attached to the larger box, so that the latter would act as a capacity and damp out all variations of pressure due to the pump.

The observations are given in Table 3, and the values obtained for a are collected together in Tables 4 and 5; the numbers being plotted with the pressure difference as abscissæ in Figs. 8 and 9.

It will be noticed that change in the diameter of the orifice has less effect on a in the case of the medium-sized box than in that of either of the others. Further, in the case of the medium-sized box the coefficient is independent of the pressure difference. A much more extended series of observations would be necessary to investigate the cause of the exceptional behaviour of the medium-sized box, and since the total change in a was small, it was not thought worth while undertaking such a serious labour. If a box of approximately the dimensions of the large box is employed, the values of the coefficient, which are given in a subsequent Table, will allow of measurements being made with an accuracy ample for the purpose intended, namely, the determination of the air-supply to an internal-combustion engine.

The Effect of Rounding the Edge of the Orifice.—It has already been mentioned that care was taken that the edges of the orifices were quite sharp, and the values given for a only apply to such cases. To see to what extent a slight rounding of the sides of the orifice would affect the value of a, plates were taken containing holes of 2 inches, 1 inch, and ½ inch diameter, and the holes rounded, at first very slightly and then more and more as shown by the drawings in Fig. 10 (page 537).

TABLE 3.

Data Observed during each Experiment with the Medium-Sized Box.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Time of Experiment.	Temperature of Air.	Barometer (corrected).	Hygrometric State.	ρ = Density of Air. Grams. per cm³.	Value of the Coefficient α.
In.		Secs.	°C.	Mm.	Mm.	0·00	
2	2·013	160	16·43	738·6	9·22	1179	0·598
,,	1·006	230	17·13	738·6	8·92	1177	0·596
,,	0·505	330	17·97	738·6	9·16	1173	0·598
,,	0·510	330	15·44	765·8	8·82	1228	0·594
1	2·001	660	12·13	747·3	7·64	1212	0·596
,,	1·010	900	13·25	747·3	7·91	1207	0·594
,,	0·514	1260	13·58	747·3	7·89	1206	0·593
0·5	2·018	510	13·25	747·3	7·82	1207	0·599
,,	1·015	720	16·28	765·8	8·84	1224	0·598
,,	0·507	1080	16·93	765·8	8·56	1221	0·598

Data Observed during each Experiment with the Small Box.

2	2·017	160	17·42	755·2	10·68	1201	0·594
,,	2·032	160	17·03	761·2	9·89	1204	0·594
,,	1·001	240	17·99	755·2	10·72	1199	0·594
,,	1·014	210	16·54	761·2	9·75	1216	0·594
,,	0·501	300	14·54	751·5	9·14	1208	0·591
,,	0·504	300	15·63	763·4	9·98	1223	0·593
1	2·019	540	14·67	751·5	9·40	1207	0·595
,,	2·000	630	13·87	751·8	7·73	1212	0·602
,,	1·005	780	14·33	764·5	10·19	1231	0·597
,,	1·012	870	13·35	751·8	7·76	1214	0·597
,,	0·501	1230	14·44	764·5	9·94	1230	0·595
,,	0·494	1200	13·07	751·8	8·08	1216	0·594
0·5	2·008	1170	14·28	766·0	9·16	1234	0·613
,,	2·037	1200	15·65	759·9	9·64	1216	0·613
,,	0·997	1710	14·38	766·0	8·85	1233	0·610
,,	1·012	1740	15·34	751·7	8·67	1206	0·610
,,	0·513	2220	12·97	772·3	7·82	1248	0·607
,,	0·511	2460	15·24	751·7	8·46	1206	0·610

TABLE 4.

Medium-Sized Box with Steady Pressure.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Co-efficient *a*.	Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Co-efficient *a*.
In.			In.		
2	2·013	0·598	1	1·010	0·594
,,	1·006	0·596	,,	0·514	0·593
,,	0·505	0·598	0·5	2·018	0·599
,,	0·509	0·594			
			,,	1·015	0·598
1	2·001	0·596	,,	0·507	0·598

TABLE 5.

Small Box with Steady Pressure.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Co-efficient *a*.	Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Co-efficient *a*.
In.			In.		
2	2·017	0·594	1	1·012	0·597
,,	2·032	0·594	,,	0·501	0·595
,,	1·001	0·594	,,	0·494	0·594
,,	1·014	0·594			
,,	0·501	0 591	0·5	2·008	0·613
,,	0·504	0·593	,,	2·037	0·613
			,,	0·997	0·610
1	2·019	0·595	,,	1·012	0·610
,,	2·000	0·602	,,	0·513	0·607
,,	1·005	0·597	,,	0·511	0·610

FIG. 10.

Showing the Different Amount of Rounding of the Edge of Orifice to obtain the Values given in Table 6.

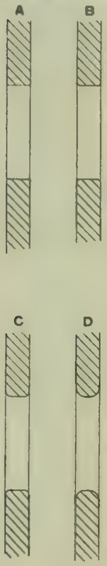


FIG. 11.

Curve giving the Value of the Factor "c" for any Value of "a."

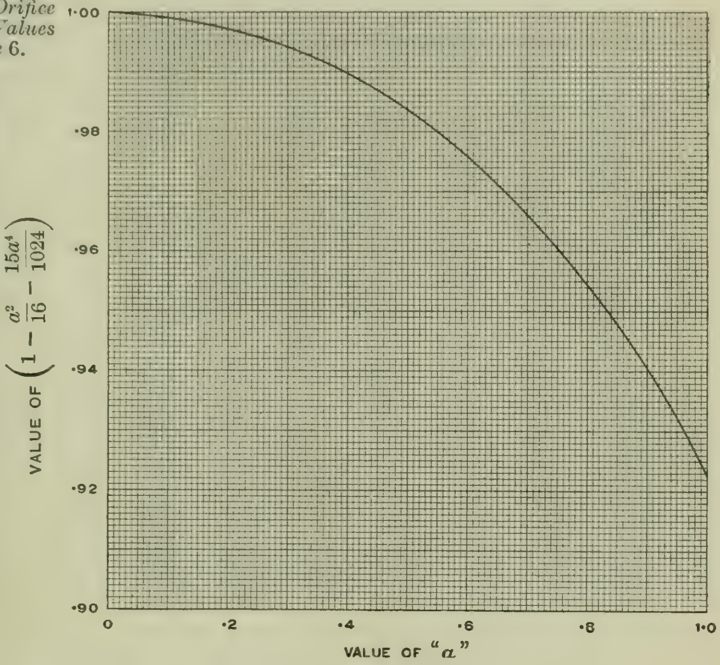


TABLE 6.—*Effect of Rounding the Orifice.*

Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Coefficient a.	Shape of Orifice.	Value of a when the Edge was quite sharp.	Percentage Change produced by Rounding.
In. 2	1·029	0·605	D	0·595	1·7
,,	1·029	0·605	D	0·595	1·7
1	1·023	0·600	B	0·599	0·2
,,	1·016	0·602	C	0·599	0·5
,,	1·007	0·610	D	0·599	1·8
0·5	1·018	0·636	D	0·607	4·8
,,	1·002	0·638	D	0·607	5·1

The values of a obtained after each successive rounding are given in Table 6, and it will be seen, if these are compared with the values for the sharp edge, that rounding the edges has an appreciable effect, particularly with the smaller holes, where it may amount to about 5 per cent. On the other hand, very slight rounding, such as might occur when attempts are made to produce a hole with sharp edges, is not likely to affect the value of a to any considerable extent.

The Effect of the Proximity of Two Orifices.—Owing to the limitation of the pump, it was impossible to experiment with orifices over 2 inches in diameter. If it is desired to measure larger rates of flow of air than can traverse such an orifice, it would be possible to use two or more orifices, in which case it is important that the disposition of the several orifices should be such, that the stream lines due to one do not appreciably affect those of the other; for if such influence takes place the values of a will certainly be affected.

To examine this point, experiments were made with two ½-inch orifices pierced in the same plate, the distance between the orifices being varied. The results are shown in Table 7.

TABLE 7.

Effect of Proximity of Two Orifices.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of the Coefficient a.	Distance between the Edges of the Orifices.
In.			In.
0·5	2·040	0·582	0·25
,,	2·045	0·584	0·50
,,	2·027	0·610	0·75
,,	2·029	0·609	0·75
,,	2·029	0·611	4·50

It will be seen from Table 7 that when the distance from centre to centre of the orifices exceeds 2·5 D, where D is the diameter of the orifice, the value of a is not affected.

Generally, the orifice was placed in the end of the box, but in some of the experiments where it was necessary to use two holes to reduce the time of filling the gas-holder, it was found convenient to place a second orifice at one side of the large box. Before doing this, several trials were run to investigate the effect of the position of the orifice upon the coefficient a. Within the limits of error of the experiments in the case of a 1-inch orifice, no difference could be detected whether the orifice was placed at the end or the side of the box, or whether the two were used together, provided there was sufficient distance between them.

The Effect of a Periodic Variation of Pressure in the Box.—Since, when this method of measuring air is used in connection with internal-combustion engines, the suction is variable, there will be a periodic variation in the pressure difference on the two sides of the orifice. Although by taking a very large box such variations can be reduced to an inappreciable extent, in many cases such a box would have to be of a very unwieldy size.

Hence a series of experiments were made to determine how the value of a varied when a cyclical variation of the pressure difference occurred. For this purpose tests were made with the boxes previously used and everything arranged as before, except that the variations in pressure produced by the pump were not damped out.

Each box was connected up directly to the pump, and the periodic variations in pressure measured by the optical indicator shown in Fig. 5 (page 527). This instrument was used to determine the amplitude of the variation of the pressure in the box, for which purpose the range of motion of the spot of light on the scale was read off. At speeds up to 300 revolutions per minute this measurement could easily be made by eye. At the higher speeds, however, it was difficult to note the maximum and minimum readings; hence a rotating disk, in which were cut slots, was placed between the eye and the scale, and the speed adjusted so that the

TABLE 8.—*Data observed during each Experiment with Large Box (Variable Pressure).*

Diameter of Orifice.	Pressure Difference. Inches of Water.	Time of Experiment.	Temperature of Air.	Barometer (corrected).	Hygrometric State.	ρ = Density of Air in Grams per cm³.	Value of the Coefficient a.	Amplitude of Variation caused by Cyclical Change in the Pressure. Inches of Water.	"a"
In.		Secs.	°C.	Mm.	Mm.	0·00			
2	0·999	240	16·35	735·9	8·05	1176	0·592	0·133	0·133
1	1·003	930	16·33	736·0	8·35	1177	0·596	0·132	0·131
0·5	0·998	1800	16·44	736·0	8·35	1176	0·609	0·139	0·140

Data observed during each Experiment with Small Box (Variable Pressure).

2	2·034	150	13·42	758·0	9·34	1224	0·579	1·26	0·62
,,	2·009	160	17·11	758·1	8·32	1209	0·580	1·24	0·62
,,	1·013	240	14·47	758·0	9·89	1217	0·573	0·80	0·79
,,	1·022	240	13·49	758·1	7·86	1224	0·575	0·80	0·80
,,	0·511	330	12·30	758·1	7·43	1229	0·577	0·35	0·69
,,	0·521	330	12·89	758·1	7·44	1226	0·576	0·32	0·61
1	1·999	660	15·91	755·7	7·59	1210	0·588	0·97	0·49
,,	2·005	660	15·48	746·1	7·03	1197	0·587	0·99	0·50
,,	1·015	930	13·65	744·8	7·18	1202	0·580	0·61	0·60
,,	1·009	960	12·96	748·0	6·50	1212	0·579	0·62	0·61
,,	0·521	1320	14·52	744·8	7·39	1198	0·577	0·36	0·70
,,	0·510	1320	13·61	748·0	6·96	1209	0·576	0·33	0·65
0·5	2·019	1260	14·10	748·0	7·19	1206	0·601	0·91	0·45
,,	1·010	1860	14·69	748·0	7·26	1203	0·589	0·63	0·62
,,	0·513	2550	15·63	731·6	7·33	1173	0·587	0·40	0·77

spot appeared to go through its cycle quite slowly, when the reading corresponding to the highest and lowest points could be made with ease.

(With the 2-inch holes at 2 inches pressure difference, the spot of light would make about 700 vibrations per minute, the actual values of the frequency for different values of the pressure difference when the small box was used are given in Table 10.)

The value of a scale division was obtained by comparing the mean of the highest and lowest readings with the value given for the mean pressure by the float type of pressure-gauge, Fig. 4 (page 526), of which the period was so great, and the connecting-pipes so small in bore, that the reading was steady. The results obtained are given in Tables 8, 9, and 10.

TABLE 9.

Large Box with Variable Pressure.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Observed Value of a.	Amplitude of the Pressure Variation. Inches of Water.	Corresponding Value of a when the Pressure is steady.
In.				
2	0·999	0·592	0·133	0·595
1	1·003	0·596	0·132	0·599
0·5	0·998	0·609	0·139	0·607

It will be seen that while for the small periodic changes obtained with the large box, the change in a is hardly appreciable, with the small box a marked effect is obtained, the value of a decreasing as the amplitude of the pressure variation increases.

This effect is probably not due to a real change in the coefficient a, since it has been shown in a previous part of the Paper that the value of a is proportional to the pressure difference. The change is really due to the fact that the actual flow of air is proportional to the mean value of the square root of the pressure

TABLE 10.

Small Box with Variable Pressure.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Observed Value of α.	Amplitude of the Pressure Variation. Inches of Water.	No. of Vibrations per Minute.	Corresponding Value of α when Pressure is steady.
In.					
2	2·034	0·579	1·26	708	0·596
,,	2·009	0·580	1·24		0·596
,,	1·013	0·573	0·80	500	0·593
,,	1·022	0·575	0·80		0·593
,,	0·511	0·577	0·35	356	0·592
,,	0·521	0·576	0·32		0·592
1	1·999	0·588	0·97	190	0·599
,,	2·005	0·587	0·99		0·599
,,	1·015	0·580	0·61	134	0·597
,,	1·009	0·579	0·62		0·597
,,	0·521	0·577	0·36	96	0·595
,,	0·510	0·576	0·33		0·595
0·5	2·019	0·601	0·91	102	0·613
,,	1·010	0·589	0·63	72	0·610
,,	0·513	0·587	0·40	52	0·608

difference, and this is not the same as the square root of the mean pressure.

We may obtain an expression to allow for this effect in the case where the pressure variation follows a simple law, in the following manner:—

Suppose the pressure difference p_1 at any time t is given by an expression of the form:—

$$p_1 = p\,(1 + a \sin \omega t),$$

where p is the mean pressure and ap is the amplitude of the variation of the pressure. The volume of air passing in a time dt is then:—

$$d v = \alpha \, F \, d t \sqrt{\frac{2 g p_1}{\rho}}$$

Hence the volume in a time t is:—

$$\begin{aligned} V &= \alpha \, F \sqrt{\frac{2 g}{\rho}} \int_0^t p_1^{\frac{1}{2}} dt \\ &= \alpha \, F \sqrt{\frac{2 g p}{\rho}} \int_0^t (1 + a \sin \omega t)^{\frac{1}{2}} dt \\ &= \alpha \, F \sqrt{\frac{2 g p}{\rho}} \int_0^t \Big(1 + \tfrac{1}{2} a \sin \omega t - \tfrac{1}{8} a^2 \sin^2 \omega t + \tfrac{1}{16} a^3 \sin^3 \omega t - \\ &\qquad\qquad \frac{5 a^4}{128} \sin^4 \omega t \, \ldots \ldots \Big) dt \\ &= \alpha \, F \sqrt{\frac{2 g p}{\rho}} \left\{ t - \frac{a^2 t}{16} - \frac{15 a^4 t}{1024} \ldots \ldots \right\} \\ &= \alpha \left(1 - \frac{a^2}{16} - \frac{15 a^4}{1024}\right) F \, t \sqrt{\frac{2 g p}{\rho}} \end{aligned}$$

if we neglect terms in higher powers of "a." This expression may be written as:—

$$V = c \, \alpha \, F \, t \sqrt{\frac{2 g p}{\rho}}$$

where "c" has the value $\left(1 - \frac{a^2}{16} - \frac{15 a^4}{1024}\right)$.

The values of this factor "c" for different values of "a" ranging from 0·05 to 1·00 have been calculated, and have been plotted in Fig. 11 (page 537). From the curve any value of "c" corresponding to a given value of "a" can be immediately scaled.

To see to what extent the numbers obtained by the use of this correcting factor agree with experience, the results obtained with the small box when the pressure was variable are compared with those calculated by means of the above expression. The comparison is shown in Table 11 (page 544).

In the last column but one are given the values of α "c," where α has the value corresponding to steady pressure differences, and "c" is the correcting factor for the pressure variation, while in the last column are given the values of the coefficient obtained by using the mean value of the pressure difference in the ordinary

TABLE 11.

Comparison of Observed and Calculated Values of a with Small Box.

Diameter of Orifice.	Pressure Difference. Inches of Water.	Value of a. Pressure Steady.	Amplitude of Vibration. Inches of Water.	Value of "c."	Value of a "c."	Experimental Values of a. Pressure Variable.
In.				From Fig. 11.		(Read off from Curve.)
2	2·00	0·596	1·24	0·9739	0·580	0·581
„	1·00	0·593	0·79	0·9553	0·567	0·574
„	0·50	0·592	0·34	0·9678	0·573	0·571
1	2·00	0·599	0·98	0·9842	0·589	0·587
„	1·00	0·597	0·61	0·9749	0·582	0·580
„	0·50	0·595	0·33	0·9700	0·577	0·576
0·5	2·00	0·613	0·90	0·9868	0·605	0·598
„	1·00	0·610	0·62	0·9739	0·594	0·590
„	0·50	0·608	0·39	0·9564	0·582	0·587

formula, that is, by neglecting the effect of the periodic changes in pressure. The agreement between the values in these two columns shows that if we multiply the value of a corresponding to a steady pressure difference by the appropriate value of "c" we can deduce a factor which will give the volume of air when used with the *mean* pressure difference.

A Comparison of Variation of Pressure due to Engine Suction with that obtained on the Experiments with the Pump.—A four-cylinder Clement-Talbot engine having a bore of 85 mm. (3·3 in.) and a stroke of 120 mm. (4·7 in.) was used. When directly coupled to the largest sized box, it was found that there was less variation produced than was obtained by the pump when giving its minimum variation, this amount being insufficient to make an appreciable difference in the value of the coefficient. Hence any effect of the factor a could be neglected in finding the air taken by such an engine using this size of box.

TABLE 12.

A Comparison of Engine and Pump Suction.

Large Box. Internal Volume = 17·36 cubic feet.

Medium Box. Internal Volume = 4·66 cubic feet.

Small Box. Internal Volume = 1·53 cubic feet.

Stroke Volume of Engine (1 Cylinder) = 41·65 cubic inches.

Stroke Volume of Pump = 172·4 cubic inches.

Size of Box.	Pressure Difference. Inches of Water.	Diameter of Orifice.	Value of "*a*" when using Pump on Tests. Tables 9 and 10.	Value of "*a*" when Measuring the 4-Cylinder Engine Suction.
		In.		
Small	2·0	2	0·62	—
,,	1·0	,,	0·79	—
,,	0·5	,,	0·65	—
,,	2·0	1	0·49	0·43
,,	1·0	,,	0·61	0·84
,,	0·5	,,	0·68	0·99
,,	2·0	0·5	0·45	0·43
,,	1·0	,,	0·62	0·96
,,	0·5	,,	0·77	0·91
Large	1·0	2	0·13	—
,,	1·0	1	0·13	0·03
,,	1·0	0·5	0·14	0·03

When the engine was coupled to the smallest box (1·53 cubic feet capacity), values of "a" as high as 0·99 were obtained, whereas the maximum value obtained with the pump was 0·79.

The tabulated values of this test are given in Table 12 (page 545). Evidently the small box would represent a minimum size that could be used on such an engine, and in that case, unless the variations in pressure were measured and a correction applied, the weight of air calculated from the formula $v = \mathrm{F}\, t\, a \sqrt{\frac{2gp}{\rho}}$ would be in error by about 6 per cent.

The connection between the stroke volume of the engine and pump, with the capacity of the boxes used, is given at the head of Table 12 (page 545).

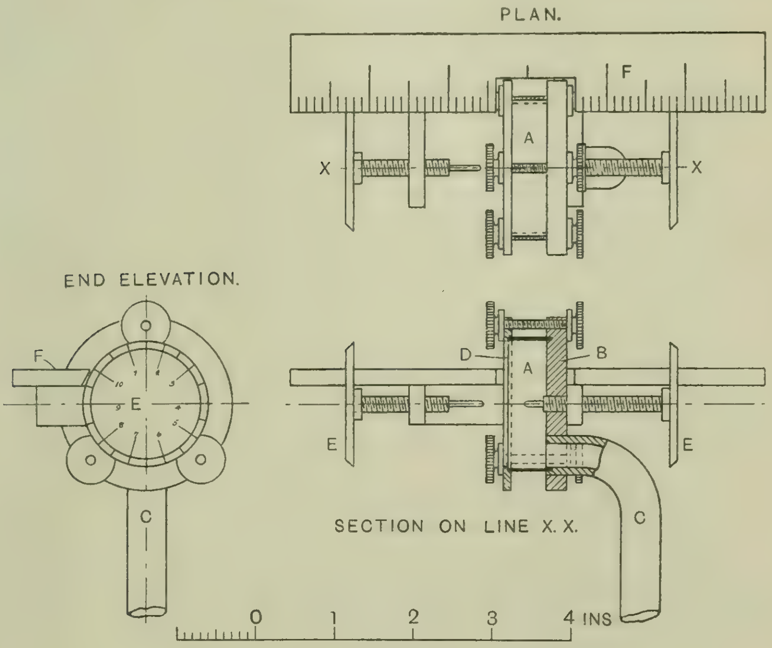
Instruments for measuring the Value of "a."—From what has been said, the importance of being able to measure the variation in the pressure will be realized. In view of this, a simple apparatus was designed which would enable the amount of the variation to be read off quickly, it being considered that the form of optical indicator used in the experiments was unnecessarily elaborate for practical use.

This gauge is shown in Fig. 12, and consists of a short glass cylinder A, closed at one end by a brass disk B connected to a pipe C, which communicates with the air-box, and closed at the other end by a very thin diaphragm D, consisting of rubber from a toy balloon. This diaphragm is held on to the top of the glass cylinder by a flanged ring, which is fastened down by three holding screws. A frame screwed to the base of the cylinder carries two micrometer screws E of millimetre pitch with divided heads, working along a scale F.

When in action the diaphragm is deflected inwards, but vibrates about a mean position. The mean position corresponds to the mean pressure difference within the box, while the difference between the extreme positions gives twice the amplitude of the pressure variation.

The zero of each micrometer is taken when the rubber diaphragm is at rest, and when it is in motion the screws are turned so that the fine points just touch the indiarubber when at the extremes of its travel. These can easily be set to 0·1 of a millimetre by observing when a slight lump appears on the opposite side of the diaphragm. If the readings are taken when this just appears and disappears, the mean will represent the true value of the displacement. By taking each side of the diaphragm in this way, and subtracting the two values so obtained, the amplitude of the variation is at once given, and a comparison between the mean value and the reading of the manometer giving the steady pressure difference in the box will serve to calibrate the deflection scale of the diaphragm.

FIG. 12.—*Gauge for measuring the Value of "a."*



If the volume of A is kept small and the connecting-tube is short and of wide bore, the rubber diaphragm will be found to follow the changes in pressure even when these take place with great rapidity.

The Calculation of the quantity of Air which passes through a Throttle-Plate.—For convenience in rapidly calculating the quantity of air which has passed through a given orifice under given conditions, the numbers tabulated in Table 13 have been calculated. The volume of air in cubic centimetres and cubic feet, and the weight of air either in grams or pounds, which would pass through an orifice of given diameter under a pressure difference of 1 inch, if the barometric height were 760 mm., the temperature of the air 15° C. (59° F.), and the hygrometric state one of half saturation, are given in the Sub-Table A (page 549). The numbers in Sub-Table A are obtained by using the values of a deduced with the large box when the pressure difference was steady. If the pressure difference is variable, the value of "a," that is the amplitude of the variation divided by the mean pressure, must be obtained, and then the value of the correcting factor "c" should be taken from Fig. 11 (page 537).

If the conditions vary from the above standard values, correcting factors are to be used to reduce the quantities given in Sub-Table A. Thus in the Sub-Table B (page 550) are given factors which correct for the amount that the pressure difference varies from the standard value taken as 1 inch. Factors in Sub-Table C (page 550) correct either the volume or the weight for temperatures differing from 15° C., and those in Sub-Table D (page 551) make the necessary correction for the barometric height differing from 760 millimetres.

In Sub-Table E (page 551) there is a factor to allow for the change in the coefficient a which is caused by the fact that the pressure difference is not 1 inch.

An example will make this method of working clear:—

Let the diameter of orifice be $1\frac{3}{4}$ inches.
Let the temperature of the air be 20° C. (68° F.).
Let the barometric height be 754 mm.
Let the difference in pressure be 0·800 inch of water.
Let the amplitude of pressure variation be 0·5 inch of water ("a"$=\frac{0\cdot5}{0\cdot8}=0\cdot62$).

TABLE 13 (pages 549–551).

SUB-TABLE A.

*Tables for Calculating the quantity of Air flowing through a Throttle-Plate.**

Calculated for :—

Time of Flow = 1 Second.
Temperature = 15° C. (59° F.).
Barometer = 760 Mm.
Hygrometric State = Half Saturated at 15° C.
Pressure Difference of 1 Inch of Water.

Diameter of Orifice.	Coefficient a.	Volume of Air Passing through Orifice (Half Saturated). Cm³.	Volume of Air Passing through Orifice (Half Saturated). Cubic Feet.	Weight of Air. (Half Saturated). Grams.	Weight of Dry Air. Grams.	Weight of Dry Air. Lb.
In.						
$\frac{3}{8}$	0·6096	867·8	0·03066	1·072	1·066	0·00235
$\frac{1}{2}$	0·6073	1553	0·05487	1·899	1·889	0·00416
$\frac{5}{8}$	0·6041	2414	0·08527	2·950	2·935	0·00647
$\frac{3}{4}$	0·6027	3469	0·1226	4·239	4·217	0·00930
$\frac{7}{8}$	0·6010	4708	0·1663	5·753	5·723	0·0126
1	0·5997	6135	0·2168	7·498	7·459	0·0164
$1\frac{1}{8}$	0·5985	7749	0·2737	9·469	9·420	0·0208
$1\frac{1}{4}$	0·5978	9557	0·3376	11·68	11·62	0·0256
$1\frac{3}{8}$	0·5971	11550	0·4081	14·44	14·37	0·0317
$1\frac{1}{2}$	0·5966	13730	0·4851	16·78	16·69	0·0368
$1\frac{5}{8}$	0·5961	16100	0·5687	19·67	19·57	0·0431
$1\frac{3}{4}$	0·5957	18660	0·6592	22·80	22·68	0·0500
$1\frac{7}{8}$	0·5954	21410	0·7563	26·17	26·03	0·0574
2	0·5951	24350	0·8602	29·77	29·62	0·0653
$2\frac{1}{8}$	0·5948	27480	0·9712	33·57	33·40	0·0736

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* A complete copy of these Tables with columns of logarithms attached, suitably arranged for use in the laboratory, may be seen at the Institution.

TABLE 13.—Sub-Table B.

—	Correction for Pressure Difference.		—	Correction for Pressure Difference.	
At Pressure Difference. Inches of Water.	Multiply Weight and Volume by	Difference.	At Pressure Difference. Inches of Water.	Multiply Weight and Volume by	Difference.
0·50	0·707		1·30	1·140	0·046
0·60	0·775	0·068	1·40	1·183	0·043
0·70	0·837	0·062	1·50	1·225	0·042
0·80	0·894	0·057	1·60	1·265	0·040
0·90	0·949	0·055	1·70	1·304	0·039
1·00	1·000	0·051	1·80	1·340	0·036
1·10	1·049	0·049	1·90	1·378	0·038
1·20	1·094	0·045	2·00	1·415	0·037

TABLE 13.—Sub-Table C.

Correction for Temperature.

At Temperature °C.	Multiply Volume by	Multiply Weight by	At Temperature °C.	Multiply Volume by	Multiply Weight by
0	0·973	1·026	16	1·001	0·998
1	0·975	1·024	17	1·003	0·996
2	0·977	1·023	18	1·005	0·994
3	0·979	1·021	19	1·007	0·992
4	0·980	1·019	20	1·009	0·991
5	0·982	1·017	21	1·010	0·989
6	0·984	1·016	22	1·012	0·987
7	0·986	1·014	23	1·014	0·986
8	0·987	1·012	24	1·016	0·984
9	0·989	1·010	25	1·017	0·982
10	0·991	1·009	26	1·019	0·980
11	0·992	1·007	27	1·021	0·979
12	0·994	1·005	28	1·023	0·977
13	0·996	1·003	29	1·024	0·975
14	0·998	1·001	30	1·026	0·973
15	1·000	1·000			

TABLE 13.—SUB-TABLE D.

Correction for Barometer.

At Barometric Height. Millimetres.	Multiply Volume by	Multiply Weight by	At Barometric Height. Millimetres.	Multiply Volume by	Multiply Weight by
730	1·021	0·980	756	1·003	0·997
732	1·019	0·981	758	1·002	0·999
734	1·018	0·982	760	1·000	1·000
736	1·017	0·983	762	0·999	1·002
738	1·015	0·985	764	0·997	1·003
740	1·014	0·987	766	0·996	1·004
742	1·013	0·988	768	0·995	1·006
744	1·011	0·990	770	0·993	1·007
746	1·010	0·991	772	0·992	1·008
748	1·008	0·992	774	0·991	1·010
750	1·007	0·993	776	0·990	1·011
752	1·006	0·995	778	0·988	1·013
754	1·004	0·996	780	0·987	1·014

TABLE 13.—SUB-TABLE E.

Correction for Variation of a with Pressure Difference.

At Pressure Difference. Inches of Water.	Multiply Weight and Volume by	At Pressure Difference. Inches of Water.	Multiply Weight and Volume by
0·50	1·003	1·30	0·999
0·60	1·002	1·40	0·998
0·70	1·002	1·50	0·998
0·80	1·001	1·60	0·997
0·90	1·001	1·70	0·997
1·00	1·000	1·80	0·996
1·10	0·999	1·90	0·996
1·20	0·999	2·00	0·995

From Sub-Table A (page 549) we see that 0·0500 lb. of dry air will pass through a $1\frac{3}{4}$-inch hole when there is a steady pressure difference of 1 inch, the temperature being 15° C. (59° F.) and barometric pressure 760 mm. (29·6 in.). We now proceed to multiply this value by the following factors:—

Factor for pressure difference (Sub-Table B) = 0·894.
Factor for temperature (Sub-Table C) = 0·992.
Factor for barometer (Sub-Table D) = 0·996.
Factor for change in coefficient (Sub-Table E) = 1·001.
Factor for variable pressure (Fig. 11, page 537) = 0·974.

Therefore the actual weight of dry air passing per second will be:—

$$\begin{aligned} W &= 0{\cdot}0500 \times 0{\cdot}894 \times 0{\cdot}992 \times 0{\cdot}996 \times 1{\cdot}001 \times 0{\cdot}974 \\ &= 0{\cdot}0431 \text{ lb.} \end{aligned}$$

The Paper is illustrated by 12 Figs. in the letterpress.

MEMOIRS.

Thomas Andrews was born at Ardara, Comber, Co. Down, on 7th February 1873, being the second son of the Right Hon. Thomas Andrews, D.L. He was educated at the Royal Belfast Academical Institution, and at the age of sixteen entered the works of Messrs. Harland and Wolff, Belfast, as a pupil. He passed through the various departments in the works and also the drawing office, showing great aptitude and industry, and during this period he studied in the evenings. After the completion of his apprenticeship his promotion was rapid and entirely due to his own ability and energy. He was appointed as one of the outside managers in the shipyard, and was subsequently given charge of the Repair Department, in which capacity his abilities were thoroughly tested, as some of the most difficult engineering achievements were supervised by him at this early age, including the lengthening of the Union liner "Scot," also the lengthening of the Hamburg-American liner "Auguste Victoria," the reconstruction of the S.S. "China" after being ashore at Perim, and a still larger operation, the reconstruction of the S.S. "Paris," which had been badly damaged on the Manacle Rocks. In the case of the last-named vessel, not only was the damage made good but the formation of the stern was completely changed and modernized; one of the three funnels was dispensed with and new engines and boilers installed. In the case both of the "China" and the "Paris" the mere docking was in itself a formidable operation, owing to the extensive damage to the bottom of the vessels. Subsequently he was given still greater managerial responsibility, and he was closely identified with the construction of all the large steamers built by the firm for the White Star and other Lines during the last ten or twelve years, including the "Celtic" (20,904 tons), "Cedric" (21,035 tons), "Baltic" (23,876 tons), "Adriatic" (24,540 tons), "Olympic" (45,324 tons), and "Titanic" (46,328 tons) for the

White Star Line; "Amerika" (22,724 tons), "President Lincoln" (18,074 tons), and "President Grant" (18,089 tons) for the Hamburg-American Line; "Nieuw Amsterdam" (16,913 tons) and "Rotterdam" (23,980 tons) for the Holland-America Line; the Red Star liner "Lapland" (18,565 tons), and other vessels. In addition to the vessels already mentioned, he was largely responsible for the design and construction of, amongst others, the following: "Aragon" (9,441 tons), "Amazon" (10,037 tons), "Avon" (11,073 tons), "Asturias" (12,002 tons), and "Arlanza" (about 15,000 tons) for the Royal Mail Steam Packet Company; "Herefordshire," "Leicestershire," "Gloucestershire," and "Oxfordshire" for the Bibby Line; the "Pericles," "Themistocles," and "Demosthenes" (each about 11,000 tons) for Messrs. George Thompson and Co., Limited's Aberdeen-Australian Line; the "Laurentic" and "Megantic" (about 15,000 tons each) for the White Star Canadian Service; also vessels for the Union Castle Line, P. and O. Co., Elder, Dempster Line, African Steam Ship Co., and Pacific Steam Navigation Co.

For many years past Mr. Andrews took a prominent part in the firm's business, crossing the Atlantic on many occasions in the large steamers of the White Star Line, from the "Oceanic" in 1899 until the last fateful trip, when he lost his life in the "Titanic," on 15th April 1912, on which occasion he displayed great heroism and splendid self-sacrifice. Knowing the ship as he alone did and its officers and crew, he could undoubtedly have saved his life, but he preferred to assist others and remained heroic to the end. At the time of his death Mr. Andrews was busy with many important shipbuilding projects, and his untimely death is felt to be a distinct loss to the profession. Being associated with an establishment so highly organized as is Messrs. Harland and Wolff, Ltd., Mr. Andrews did not take out any mechanical patents, but he was thoroughly familar with and responsible for many of the latest labour-saving devices and arrangements for securing economy and efficiency of work. His knowledge of naval architecture embraced electrical and mechanical engineering as well as marine engineering, his experience of all the complicated and intricate machinery and arrangements necessary in the construction and equipment of modern steamships being altogether exceptional. In addition to the part taken by him in connection with large vessels, he also designed and supervised the construction of some of the latest and most successful smaller steamers, notably the "Heroic," "Graphic," and "Patriotic" for the Belfast and Liverpool route; the "Slieve Bawn" for the Greenore and Holyhead service; the passenger and baggage tenders "Nomadic" and "Traffic" for service at Cherbourg; the "Berbice" and "Balantia" for the Royal Mail West Indian Intercolonial trade; and one of the last ships which he designed was the new pleasure steamer "Erin's Isle" for the Belfast and County Down Railway Co. Notwithstanding the exactions of his own business he occasionally found time to execute a special commission, such as the investigation of the harbour facilities at Halifax and in the St. Lawrence, also in British and Continental ports; and some years ago on behalf of his uncle, Lord Pirrie, he made an extensive survey of the chief harbours of Ireland. He was thirty-nine years of age. He became a Member of this Institution in 1902.

SIDNEY ANGELO BEIRNE was born in London on 21st June 1876. After being educated privately he went through a two years' training at the East London Technical College, taking the engineering course. In 1890 he commenced a pupilage with Mr. Frederick Kensington, consulting engineer, of Westminster, and on its completion in 1897 he continued in the same employment until 1899. In July of that year he went to Spain in the service of the San Salvador Spanish Iron Ore Co., and was engaged on survey work, plans, &c., on the various extensions of the Company's railways, ore-dressing plant, and the reclamation of marsh land. He continued in the Company's employ until his death, which took place at Astillero, Province of Santander, in June 1911, at the age of thirty-five. He became an Associate Member of this Institution in 1902.

EDWARD ERNEST GEORGE DAVEY was born in London on 11th October 1860. His education was received at various private schools from 1868 to 1875, when he entered the works of Messrs. Benham and Sons, engineers, of Wigmore Street, London, and served until 1881. Then he entered the drawing office as a junior draughtsman, eventually becoming leading engineering draughtsman, and remained in their employ until 1898. During that later period he was responsible for the designs of engines, boilers, pumps, accumulators, lifts, laundry machinery, &c., superintending their manufacture and in some cases their erection. In addition to this work he was from 1888 assistant lecturer on Machine Drawing and Construction at the Polytechnic, Regent Street, London, and for two years lecturer at the Enfield Science School and the Charterhouse on the same subjects. Owing to ill-health he retired from the Polytechnic in 1909, and went to live at Leigh-on-Sea, Essex, where his death took place after a long illness on 30th May 1912, at the age of fifty-one. He became an Associate Member of this Institution in 1894.

JOHN DODD was born at Oldham on 7th August 1837. His engineering training was obtained in the works of Messrs. Platt Brothers and Co., textile machinery manufacturers, of Oldham, with which firm he was associated all his life. He went through the works, first in the pattern shop, and next as a fitter. Gradually he rose by virtue of ability, hard work, and an excellent education, and for the last thirty years he had been a director. On the death of Mr. Samuel R. Platt * in 1902 he succeeded him as Chairman of the company. This post was no light burden for a man of Mr. Dodd's age and his habit of personally supervising its administration, which comprised: Hartford Old Works, Hartford Forge, Hartford Sawmills, Werneth Spindle Works, Hartford New Works, and Collieries. For twenty-three years he was a member of the Council of the Chamber of Commerce; and he was greatly interested in all matters that affected the industries of the town generally. He was a Justice of the Peace for the town of Oldham. His death took place suddenly at his residence at Werneth Park, Oldham, on

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* Proceedings, Inst.Mech.E., 1902, Part 5, page 1033.

13th April 1912, in his seventy-fifth year. He became a Member of this Institution in 1880.

JOHN GWYNNE was born in Ireland on 14th January 1837. He was educated at Bruce Castle and Esher, and entered his father's Essex Street Engineering Works as an apprentice in 1853. In 1867, in conjunction with his brother Henry, he founded the Hammersmith Iron Works for the manufacture of centrifugal pumping machinery, the title of the firm being J. and H. Gwynne, and under this title they carried on business for thirty years. In 1897 the concern was converted into a limited company, and six years later the ancient engineering works of Messrs. Gwynne and Co., Essex Street and Brooke Street, were united with the firm of J. and H. Gwynne, under the direction of Mr. John Gwynne, the present name of the firm, Gwynnes, Limited, being then adopted. It continued actively to progress under his direction, and he personally carried out in various parts of the world many important and successful contracts for pumping plants, drainage and irrigation machinery, in conjunction with several of which he received a number of distinctions. His death took place at his residence, Kenton Grange, near Harrow, Middlesex, on 2nd May 1912, at the age of seventy-five. He became a Member of this Institution in 1870; he was also a Member of the Institution of Civil Engineers.

NORMAN HARRISON was born in Liverpool on 15th September 1873. His education was obtained at the Northern Institute in that city, and then at the age of fifteen he commenced a five years' apprenticeship with Messrs. Higginson and Co., of Liverpool. On its completion in 1894 he entered the service of Messrs. Elder, Dempster and Co., becoming successively Fourth, Third, and Second Engineer. Four years later he transferred his services to Messrs. Ismay, Imrie and Co., owners of the White Star Line of steamships, for whom he acted as Third and Second Engineer on some of their largest boats. Early in January 1912 he was recalled from the R.M.S. "Adriatic" and sent to Belfast to join the

"Titanic," the latest vessel of the White Star Line and the largest afloat at the time. While on its maiden voyage to New York the vessel struck an iceberg on 15th April 1912, and foundered within four hours. This terrible accident was accompanied by great loss of life, not one of the engineering staff being among the survivors. Mr. Harrison was in his thirty-ninth year. He was elected an Associate Member of this Institution in 1911.

WILLIAM EDWARD HIPKINS was born in 1858. He was first educated at the Birmingham Grammar School, and then from 1872 to 1875 by private tutors while travelling in the United States and on the Continent. In the latter year he commenced an apprenticeship in the works of his father, who was a machinist and engineers' tool-maker in Birmingham. On its completion in 1880 he went into the drawing office for three years, and in 1883 became assistant manager. Three years later he was appointed manager, which position he held until 1889. During the next five years he was manager for Messrs. J. and E. Wright, steel-rope manufacturers and cableway engineers, Birmingham. In 1895 he became manager of the Soho Foundry, Birmingham, of the firm of James Watt and Co., formerly Boulton and Watt, and he was also managing director of Messrs. W. and T. Avery, weighing machinists and engineers. He was travelling to America on the S.S. "Titanic," and was one of the numerous ill-fated passengers who perished on its foundering on 15th April 1912. He was fifty-four years of age. He became a Member of this Institution in 1898.

CHARLES HODGSON was born at Brighton on 13th May 1842. He served an apprenticeship of five years in the locomotive works of the London, Brighton and South Coast Railway at Brighton, and on its termination was engaged as draughtsman in the same works for about three years. During the latter part of this time he was head draughtsman, having charge of the drawing office. He then joined Mr. Saxby and Mr. Farmer when they entered into partnership in the signalling business. For many years he was general manager, and in 1893 he was appointed Managing Director on the conversion of the firm into a company; he subsequently occupied the additional position of Chairman. Many inventions in the signalling business stand to his credit, the chief among them being his electric lock and block system. His death took place at his residence at Cricklewood, London, on 20th April 1912, in his seventieth year. He became a Member of this Institution in 1880.

Henry Bryant Howe was born on 1st June 1840. At the age of nine years he accompanied his parents to Sydney, New South Wales, where he resided all his life. Having served an apprenticeship of seven years, he was engaged on millwright and marine work by Messrs. P. N. Russell and Co., Sydney. In 1861 he left this firm to take charge of the large saw-milling plant of Messrs. Wilkinson Brothers, and was their engineer-in-charge for several years. Two years later he assisted Mr. E. D. Nicolle in perfecting and erecting the first ammonia ice-making machine in the colony of New South Wales. In 1864 he joined the New South Wales Railway service as a mechanic in the machine shop at Eveleigh, and soon afterwards he became one of the leading hands in charge of repairs. In 1871 he was appointed foreman of the turning and machine shops, and later was promoted to be general foreman of the workshops. In 1883 Mr. Howe was transferred to the Randwick steam tramway workshops as assistant locomotive superintendent, and remained in this position until 1889, when he returned to the Eveleigh locomotive shops to take charge as general works manager, a post he filled up to the time of his retirement in December 1910. On two occasions he had visited America on behalf of the Railway Commissioners, and as a result the Railway Department profited largely from his observations and recommendations. When at a later date it was decided to build the engines at Eveleigh, Mr. Howe was entrusted with the work of installing the plant and starting the scheme, which proved a financial success. Apart from his duties as works manager, he devoted much spare time to other railway matters, such as the advancement of the Railway Educational Centre and the Institute. For two years he held the position of President of the Engineering Association of New South Wales. On his retirement from the railway service at the end of 1910 he commenced practice as a consulting engineer and acted as the representative of the Baldwin Locomotive Company of America. But ill-health overtook him and he was forced to retire. His death took place at his residence at Kensington, Sydney, on 16th April 1912, in his seventy-second year. He became a Member of this Institution in 1901.

THOMAS BRIGHT MATTHEWS was born in Sheffield on 20th May 1844, being the son of the late Mr. W. A. Matthews, who was Mayor and Master Cutler of Sheffield. He was a partner in the firm of Messrs. Turton Brothers and Matthews, of Sheffield, until the year 1897, when the business was converted into a private company. He then became one of the managing directors, which position he retained for several years. For the last twenty years he had resided at Thorp Arch Hall, Thorp Arch, Yorkshire. His death took place at Hanbury, near Burton-on-Trent, on 30th May 1912, at the age of sixty-eight. He became an Associate of this Institution in 1868.

Alderman MARK WILLIAM SWINBURNE, Mayor of Wallsend-on-Tyne, was born at Newcastle-on-Tyne on 3rd August 1836. He served his apprenticeship as an engineer with Messrs. W. G. Armstrong and Co., Elswick Works, and subsequently became manager for Messrs. Henry Watson and Sons, High Bridge, Newcastle-on-Tyne. For twenty-five years he held this position, and then in 1891 he commenced business at Wallsend under the title of M. W. Swinburne and Sons, engineers, brassfounders, and coppersmiths, their speciality being brass work for ships and marine engines. Only in recent years did he take part in municipal matters, when he was elected a member of the Wallsend Town Council. In 1910, after the enlargement of the borough, he was unanimously elected Mayor, and in November 1911 he was re-elected, being appointed an Alderman. He was also a Justice of the Peace for the Borough of Wallsend. His death took place, after a short illness, at his residence in Jesmond, Newcastle-on-Tyne, on 23rd May 1912, in his seventy-sixth year. He became a Member of this Institution in 1882; he was also a Member of the North-East Coast Institution of Engineers and Shipbuilders.

Walter Chapman Wood was born at Bolton on 14th December 1855. He was educated at the Church Institute, Bolton, and Clevedon College, Northampton. In 1872 he commenced an apprenticeship of five years with Messrs. Barlow and Jones, of Bolton, and on its completion he was appointed an assistant manager. In 1886 he became manager of the Garfield Mills, Bolton; and in the following year occupied a similar position with Messrs. George Hodgkinson and Sons, Bolton. He went out to India in 1893 to take up the appointment as manager of the Peervo Mahomed Cotton Mills, Bombay, and subsequently became Honorary Examiner in Cotton Spinning at the University of Bombay. Three years later he proceeded to Shanghai, where he became manager of a cotton-mill; and then went to Soochow in a similar capacity. During the Boxer rebellion he kept the mill working, being the only European in the city. In 1903 he accepted the appointment of manager of the International Cotton Spinning Co., Shanghai, and remained there until ill-health caused his retirement in 1910. His death took place at Westcliff-on-Sea, Essex, on 27th May 1912, at the age of fifty-six. He became a Member of this Institution in 1896.

INDEX.

1912.

Parts 1–2.

Abbey, C. G., elected Graduate, 313.

Abstracts of Technical Literature, 90.

Accounts, 87, 96–101.

Adamson, D., Remarks on Annual Report, 134:—on Examinations, 162.

Address, Coronation, to King George V, 85.

Ahrbecker, H. V. C., Decease, 86.

Airedale, Lord, P.C., Decease, 86.

Air-Supply to Internal-Combustion Engines, Measurement of, by Throttle-Plate, *Paper* by W. Watson and H. Schofield, 517.—Previous experiments, 517.—Description of apparatus and method of experiment, 518.—Gas-holder, 521.—Air-boxes, 524.—Diaphragms, 524.—Measurement of pressure difference, 525.—Method of making the trials, 528.—Method of testing for leaks, 530.—Experiments with no cyclical variation in the pressure difference, 530.—Data observed during each experiment with large box, 531.—Effect of rounding edge of orifice, 534.—Experiments with medium-sized box, 535.—Effect of proximity of two orifices, 538.—Effect of a periodic variation of pressure in box, 539.—Variable pressure experiments, 540–3.—Comparison of engine and pump suction, 545.—Calculation of quantity of air passing through a throttle-plate, 548–552.

Allen, C., elected Member, 174.

Allen, R. W., Remarks on Turbine-Pump, 49.

Allen, W. H., Benevolent Fund, 88.

Alleyne, Sir J. G. N., Bart., Memoir, 299.

Allin, H. P., elected Associate Member, 3.

Alloys Research, 89.

Alloys Research, *Tenth Report* to the Alloys Research Committee: On the Alloys of Aluminium and Zinc (with an Appendix on a Ternary Alloy of Aluminium with Zinc and Copper), by W. Rosenhain and

S. L. Archbutt, 319.—General introduction, 323.—Summary of principal results: Constitution of the alloys, 327; study of the cast alloys, 328; study of the wrought alloys, 330.

Main Report: Plan of research, 337.—Constitution of alloys, 337; equilibrium diagram of AlZn alloys, 338; typical cooling curves, 343.—Study of the cast alloys: aluminium, 344; zinc, 344.—Preparation of the alloys, 344.—Melting the alloys, 344.—Composition of cast alloys, 347.—Tensile tests on cast alloys: sand-castings, 348; ageing of sand-castings, 352.—Tensile tests on chill-castings, 353; ageing tests, 354.—Chill-castings, 354.—Specific gravity of alloys, 356.—Specific tenacities, 360.—Compression tests, 362.—Microstructure of the sand-cast and chill-cast alloys, 365.—Study of the wrought alloys, 368.—Behaviour of the alloys on rolling, 369; on cold-drawing, 371; on rolling into sheets, 371.—Tensile tests: material hot-rolled to 1¼ inch diameter, 373; on bars hot-rolled to ½ inch diameter, 379.—Comparison of tests on annealed material, 386.—Tensile tests on cold-drawn and annealed wires, 393; on sheets, 396.—Summary of Tensile Tests, 400.—Further study of the alloys, 400.—Tensile tests at high temperatures, 408.—Determination of the elastic properties of the alloys, 417.—Autographic stress-strain diagrams, 420.—Torsion tests, 422.—Hardness numbers, 425.—Compression tests, 426.—Dynamic tests, 428.—Alternating-stress tests, 430.—Alternate-bending impact tests, 431.—Single-blow impact tests, 433.—Arnold's alternate-bending test, 434.—Corrosion tests, 436.

Appendix.—Properties of a ternary alloy of aluminium with zinc and copper, 441; tensile tests on this alloy, 442.

Discussion on 19*th April* 1912.—Ellington, E. B., Thanks to authors, 445.—White, Sir W. H., Remarkable range and character of Reports, 445; future discoveries; necessity for studying microscopic details, 446; effect of small variations in physical conditions of metals; practical point of view of research, 447.—Muntz, Sir G. A., Curious properties of Duralumin probably caused by magnesium, 449; high specific gravity with 26 per cent. zinc alloy; effect of rolling on structure of zinc rod, 450; use of pure zinc, 451; corrosion of aluminium, 452.—Huntington, A. K., Making of sand-castings for test-pieces, 452; effect of chill on castings, 454.—Morrison, W. M., Collaboration of scientific with practical men, 454.—Fowler, H., Preliminary tests by users before publishing Reports, 455.—White, Sir W. H., Local pitting in corrosion tests, 455; assistance rendered to Research Committee by leading firms, 456.—Archbutt, L., Corrosion experiments, 457.—Donaldson, Sir H. F., Casting temperature too low for foundry use, 458; comparative results obtained at Woolwich Arsenal, 459-461.

Discussion on 3rd May 1912.—Archbutt, S. L., Effect of using ordinary foundry spelter instead of pure zinc, 462; comparative results, 463; measurement of contraction of castings, 464.—Arnold, J. O., Importance of AlZn alloys for aviation purposes, 464; influence of temperature on mechanical tests; influence of trace of bismuth on gold, 465; accuracy of elastic-limit curves; alternating-stress tests, 466; collaboration of Universities with practical metallurgists, 467.—Mills, W., Pioneer work in AlZn alloys, 467; demand for light alloy; some bad properties of these alloys; contraction, 469; corrosion; ageing of metals, 470; specific tenacity, 371.—Harbord, F. W., Cracking of castings; corrosion and disintegration from ageing, 472; duplicate tests necessary; size of bars, 473; cause of discordant results, 474; corrosion tests in air, 475.—Law, E. F., Abnormal corrosion due to impurities, 476; effect of ageing, 477.—Sankey, Capt. H. R., Importance of correct casting temperature, 478.—Graham, R. F., Unaccountable results with alloys, 478.—Armstrong, P. A. E., Lubricant necessary for machining castings, 478; hot dies for pressing, 479; trouble from abrasion, 480.—Ellington, E. B., Researches carried out on scientific lines with a view to practical results, 480.—Rosenhain, W., Pioneer research, 481; Duralumin; ageing tests, 482; possible use of alloys in large structures, 483; necessity for static tests for heavy structures, 484; table of ratios for beams of similar cross-sections, 485; corrosion tests, 487; low casting temperatures for foundry work, 488; influence of casting temperature, 490; method of measuring temperatures, 491; impurities in zinc; correlation of static elastic limits with Wöhler tests, 492; specific tenacity, 493; duplicates of tests, 494; dimensions of test pieces; difficulty of machining alloys, 495.

Communications.—Bubb, H. J., Impurities in zinc, 496.—Hadfield, Sir R. A., Ageing tests; effect of blows on some alloys, 497.—Lantsberry, F. C. A. H., Adverse effect of work on alloys, 498; Duralumin, 499.—McKechnie, J., Description of Duralumin, 500–4.—Seligman, R., Lack of brittleness, 504; rolling and drawing of alloys, 505; liability to corrosion, 506; alloys useful for culinary purposes, 507.—Sumner, L., Tests with ordinary spelter necessary, 508.—Wingfield, C. H., Definition of specific tenacity, 508; qualities claimed for binary alloys, 510; effect of ageing; hardness; equilibrium diagram, 511.—The Authors, Water-quenching, 511; dynamic tests, 512; corrosion specimens; commercial spelter; sensitiveness of alloys to hot rolling, 513; specific tenacity; preparation of rolled bars, 514; hardness; equilibrium diagram, 515.

Aluminium-Zinc Alloys, 319. *See* Alloys Research, *Tenth Report.*

American Society of Mechanical Engineers, Illuminated Address from, 85.

Anderson, J., Decease, 86.

ANDREW, H. M., *Calcutta Section Paper* on The Evolution of Valves and Safety Appliances for Boilers, 93.
ANDREWS, T., Memoir, 553.
ANGLES, J. W., elected Associate Member, 175.
ANGUS, J. A., elected Member, 174.
ANNUAL GENERAL MEETING, Business, 81.
ANNUAL REPORT OF COUNCIL, 85. *See* Council, Annual Report.
APPLEBY, G. W., Decease, 86.
APPLEYARD, F., elected Member, 174.
APRIL MEETING, 1912, Business, 311.
ARCHBUTT, L., Remarks on Alloys Research, 457.
ARCHBUTT, S. L., *Tenth Report* to the Alloys Research Committee: On the Alloys of Aluminium and Zinc, 319.—Remarks thereon, 462, 463, 511.
ARMSTRONG, P. A. E., Remarks on Alloys Research, 478.
ARNOLD, J. O., Remarks on Alloys Research, 464, 467.
ASHCROFT, A. G., Decease, 86.
ASHTON, H. T., Decease, 86.
ASLETT, E. S., elected Graduate, 176.
ASSOCIATE MEMBERSHIP EXAMINATIONS, Scheme, 89, 124–133. *See* Discussion on Annual Report.
ATHERTON, W. H., Remarks on Turbine-Pump, 52.
ATKINSON, A., Decease, 86.
ATKINSON, R. C., elected Associate Member, 175.
ATTACK, A. M., Remarks on Turbine-Pump, 60.
AUDITOR, Appointment, 84.
AUSTIN, E. G., Memoir, 300.
AVILA, J. F., elected Associate Member, 175.
AYKROYD, J. K., Remarks on Examinations, 153.

BACKHOUSE, J., Associate Member transferred to Member, 82.
BAGSHAWE, B. W., *Calcutta Section Paper* on The Burning of Fuel by the Underfeed System of Firing, 93.—Remarks on Diesel Oil-Engine, 293.
BAINBRIDGE, A. W., elected Associate Member, 312.
BAINBRIDGE, E., Decease, 86.
BAKER, W. G., elected Associate Member, 312.
BALDWIN, C. E., Remarks on Examinations, 145.
BAMFORD, W., elected Associate Member, 312.
BAMLETT, A. C., Memoir, 301.
BARKER, M. W., Memoir, 302.
BARR, A., re-elected Member of Council, 82.
BARR, J. A., elected Graduate, 4.
BARRETT, H., Decease, 86.

Barry, D., elected Member, 174.
Barsdorf, H., elected Member, 174.
Beale, F., elected Associate Member, 175.
Beck, J. W., elected Graduate, 313.
Beirne, S. A., Decease, 86.—Memoir, 555.
Bell, Lt.-Col. C. T., R.A., Remarks on Examinations, 171.
Benevolent Fund, 88.
Benny, H. B., elected Graduate, 176.
Bentley, H., elected Graduate, 176.
Bergin, J. J., elected Associate Member, 175.
Bicknell, A. C., Decease, 86.
Birks, L., elected Member, 174.
Black, G. J. F., elected Member, 174.
Black, J., elected Associate Member, 312.
Blanchard, L. W., Remarks on Examinations, 171.
Bousfield, A. J., elected Associate Member, 3.
Bremner, A. J., Awarded Graduates' Prize, 82, 93.—*Graduates' Paper* on The Balancing of Engines, 93.
Briggs, E. R., Remarks on Diesel Oil-Engine, 252.
Briggs, J. C., *Graduates' Paper* on Requirements of Illumination and the Status of Gas Lighting, 93.
Britten, T., Associate Member transferred to Member, 82.
Britten, T. J., Decease, 86.
Brodie, E. D., elected Graduate, 176.
Broughton, H. H., Remarks on Examinations, 166.
Brown, A., Remarks on Annual Report, 140:—on Examinations, 150.
Brown, B. H., elected Associate Member, 175.
Brown, G. S., elected Associate Member, 3.
Bruce, D. C., elected Associate Member, 175.
Bryan Donkin Fund, Accounts, 101.—Regulations for Second Award, 103.
Bubb, H. J., Remarks on Alloys Research, 496.
Buckley, S., elected Member, 174.
Burton, T. B., elected Member, 174.

Calcutta and District Section, 92.—Papers and Visit, 93.—Officers, 93.
Calvert, R., elected Member, 311.
Campbell, H., Remarks on Examinations, 167.
Carnegie, E., elected Associate Member, 175.
Chorlton, A. E. L., *Paper* on the Evolution of the Turbine-Pump, 7.—Remarks thereon, 55, 68.
Chowna, P. D., elected Associate Member, 175.
Churchill-Shann, M. H., Remarks on Diesel Oil-Engine, 258.

Churchward, G. J., re-elected Member of Council, 82.

Clark, H. A., Remarks on Diesel Oil-Engine, 246.

Clark, Major R. L., D.S.O., elected Member, 311.

Clerk, D., Remarks on Diesel Oil-Engine, 231.

Clews, R. T., elected Graduate, 313.

Cochrane, G., Decease, 86.

Cockey, Eng.-Com. G. H., D.S.O., elected Member, 311.

Coker, E. G., Remarks on Examinations, 167, 171.

Colborne, T., elected Member, 3.

Collingham, E. B., elected Associate Member, 3.

Collins, C. A., Awarded Graduates' Prize, 82, 93.—*Graduates' Paper* on The Manufacture of Interchangeable Parts, 93.

Constantine, E. G., Remarks on Examinations, 147.

Cooke, C. J. B., elected Member, 311.

Copper-Aluminium-Zinc Alloy, 319.—*See* Alloys Research, *Tenth Report.*

Copping, G. L., *Graduates' Paper* on Air Movers, 93.

Corfe, A. W., elected Graduate, 176.

Coronation Address to King George V, 85.

Corrin, H. R., elected Member, 311.

Council, Annual Report, 85.—Honours, 85.—Coronation Address to King George V, 85.—Illuminated Address from American Society of Mechanical Engineers, 85.—Number of Members, etc., 86.—Deceases, 86.—Financial statement, 87, 96–101.—Extension of Institution Building, 88.—Benevolent Fund, 88.—Examinations for admission, 89. —Alloys Research, 89.—Gas-Engine Research, 89.—Representation of Institution on other Organizations, 90.—Loan of Hall to other Societies, 90.—Donations to Library, 90, 105–123.—Engineering Abstracts, 90.—Zürich Summer Meeting, 91.—Meetings and Papers, 91.—Lectures on Steel, 92.—Calcutta and District Section, 92.—Graduates' Meetings and Papers, 93.—Invitations to Graduates from local Engineering Societies, 93.—Vote of Thanks to Mr. Arthur Keen on retiring from Vice-Presidency, 94.—Appendix of Draft Scheme for Associate Membership Examinations, 124.—Note thereon by the President, 131.

Discussion on Annual Report.—Donaldson, Sir H. F., Scope of Discussion, 134.—Adamson, D., Provincial members, 134; Research, 135; abstracts of technical literature, 136; Local Sections; Council membership, 138: one-year Presidency, 139.—Marks, E. C. R., Local Sections, 139.—Brown, A., Abstracts, 140; lectures; Benevolent Fund, 141.—Donaldson, Sir H. F., Research; abstracts, 142; Presidency; Local Sections; Benevolent Fund, 143; motion for adoption of Report, 144.—Maw, W. H., Seconded motion, 144.—Motion carried, 144.—

Baldwin, C. E., Advantage of holding provincial Meetings, 145.—Roberts, D. E., Local Sections in South Wales, 145.

Discussion on Examinations Question.—Donaldson, Sir H. F., Explanation of scheme, 146.—Constantine, E. G., Raising of status of membership, 147.—Raworth, B. A., Methods of attaining Associate Membership, 148; dangers to be guarded against, 150.—Donaldson, Sir H. F., Suggested Resolution, 150.—Brown, A., Position of young apprentices, 150.—Hunter, C. F., Modification of syllabus, 152.—Aykroyd, J. K., Examinations for Graduates, 153; syllabus of examination, 154.—Wainwright, J. W., Nature of examination questions, 155.—Spooner, G. P., Technical education in Germany, 155.—Smith, S. A., Point of view of Graduates, 156; limit of age for examination, 158; exemptions, 160.—Fryer, J. E. G., Exemption from examination, 161.—Adamson, D., Suggested ballot of members on Examinations Question, 162.—Gardner, A. C., Discussion of details should be postponed, 162.—Davey, H. N., Economics should be included in syllabus, 162.—Donaldson, Sir H. F., Examination for Graduates, 163; all members had been notified of scheme, 163; Resolution moved, 164.—Marks, E. C. R., Seconded Resolution, 164.—Resolution carried, 165.

Communications.—Broughton, H. H., Examinations should be taken early; nature of syllabus, 166.—Campbell, H., Objections to examinations, 167.—Coker, E. G., Prevention of cramming; recognized Colleges, 167.—Darling, H., Technical Knowledge syllabus, 168.—Dixon, W., Objections to examinations, 168.—Hall, A. H., Prevention of cramming, 168.—Pritchard, W. E., Examinations of University standard, 169.—Royds, R., Syllabus of Technical Knowledge, 169.—Sams, J. H., Commercial Engineers, 169.—Suggestions as to Examinations to be placed upon Exempting List, 171.—Bell, Lt.-Col. C. T., Thesis necessary for all candidates, 171.—Fawcett, E. G. D., Physics and Chemistry should be optional, 171.—Griffith, P., Unification of competing examinations, 172.

COUNCIL APPOINTMENTS, 173.

COUNCIL, Retiring List, and Nominations for 1912, 1.

COUNCIL for 1912, 83.

COUSIN, A. N., elected Graduate, 4.

CRABTREE, W. S., elected Associate Member, 3.

CREAK, R. B., elected Member, 3.

CRIGHTON, C., elected Member, 174.

CRIPWELL, F., elected Member, 311.

CROFTON, E. V. M., elected Graduate, 4.

CROFTS, J. C. T., Decease, 87.

Croll, J., Decease, 87.
Cronk, N. T., elected Associate Member, 3.
Cross, W. M., Associate Member transferred to Member, 177.
Crossley, Sir W. J., Bart., Decease, 87.
Cunningham, J. C., elected Member, 174.

Darbishire, J. T. D., elected Graduate, 313.
Darling, H., Remarks on Examinations, 168.
Dashper, E. H., elected Member, 311.
Davey, E. E. G., Memoir, 555.
Davey, H. N., Remarks on Examinations, 162.
Davidson, W., Decease, 87.
Davies, B. T., elected Associate Member, 312.
Davison, W., elected Graduate, 176.
Dawson, T. S., Remarks on Diesel Oil-Engine, 289, 295.
Deceases of Members, 86.
Deceases of Members of Council, S. W. Johnson, 1:—T. P. Reay, 173.
De Gruchy, W. A., elected Associate Member, 3.
Dewrance, J., nominated for election as Member of Council, 2.
Dickson, H. S., elected Graduate, 313.
Diesel, R., *Paper* on The Diesel Oil-Engine, and its Industrial Importance, particularly for Great Britain, 179.—Remarks thereon, 254, 275.
Diesel Oil-Engine, *Paper* on The Diesel Oil-Engine, and its Industrial Importance, particularly for Great Britain, by R. Diesel, 179.—Scope of Paper, 179.—Heat consumption of different heat-engines per b.h.p.-hour, 180.—Map of petroleum fields of the world, 183.—Production of oil exceeds the demand; utilization of tar and creosote oils, 184; variation in quality of tar-oils, 185; gas-tar oils; brown coal and lignite, 186; oils from earth-nut; tests therefrom, 187.—Working diagrams of single-acting Diesel engines, 188.—Historical summary, 189: Four-stroke cycle engine: vertical stationary engines, 189; small engines, 194; horizontal stationary engines, 194.—Two-stroke cycle engines, 195.—Marine engines, 200.—Conclusions, 203.—Special importance of the Diesel engine for Great Britain, 205; Great Britain is an exclusively coal-producing country, 205; Great Britain has the largest Colonial Empire in the world, 206; Great Britain is the greatest Shipping Nation in the world, 207.—Appendix I: Suitable oils, 208.—Appendix II: Specifications of tar-oil suitable for Diesel engines, 210.—Appendix III: Properties of pit-coal tars, 212.—Appendix IV: List of vessels propelled by Diesel engines, 216.—Appendix V: Brief results from some vessels propelled by Diesel engines, 219.—Appendix VI: Motor-boat shipping in the Colonies, 224.

Discussion.—Donaldson, Sir H. F., Thanks to author, 230.—Clerk, D., Early difficulties in development of internal-combustion engine, 231; action of 1887 flame-injection engine, 232; indicator diagrams therefrom, 234; Dr. Diesel's indicated efficiencies too high, 236; efficiency of 35 per cent. with gas-engine, 237; advantage of Diesel engine lies in its capacity to burn crude oils, 237; table of weights of large gas-engines, 238; particulars of various gas-engines, 241; size of cylinders, 242.—Joy, B. H., Auxiliary engines of sailing ship, 243; four-stroke and two-stroke cycle engines for marine purposes; difficulties with double-acting engines, 244; Diesel and Sabathé engines; effect of tar-oils and shale oil on piston-rings, 245.—Clark, H. A., Tanner's two-cycle double-acting Diesel engine, 246.—Robinson, M., Importance of utilizing by-products of coal, 249.—Russell, H. S., First Diesel engine (1897) in Great Britain still working efficiently, 249; Continental and British engines, 250; weight of engines, 251.—Briggs, E. R., Future development, 252; Willans-Diesel engine, 253; influence of automatic machine-tool, 254.—Diesel, R., Difference between Diesel and Clerk engines; calculation of thermal efficiency, 254; Nuremberg accident, 255; two-cycle versus four-cycle engines; Sabathé engine; tar-oils, 256; British engines, 257.

Communications.—Churchill-Shann, M. H., Semi-Diesel engine, 258; compound expansion of hot gases, 259.—Erith, C., Advantages of steam turbo-generator for electrical power plants, 260; limited scope of crude-oil engine, 261.—Houston, P. T., Yearly output of mineral oil, 262; marine gas-engines, 263; fuel cost of "Toiler" and "Vulcanus," 264; difficulty of effecting repairs to Diesel engines abroad; fuel cost, 265.—Wainwright, J. W., Performance of Diesel ship "Selandia," 266.—Willcox, R. J. N., Rigidity of sole-plate of "Selandia," 269; piston cooling, 270; risks of fire to property from use of crude-oil, 271; leakages of oil and inflammable vapour therefrom, 272; requirements for fire prevention, 273.—Wilson, J. V., Lubrication, 273; advantages from using compound oils; carbonization, 274.—Diesel, R., Experimental 150-h.p. compound engine, 275; central electrical station plant; annual consumption of oil, 276; tank-ship propulsion; gas-engines not competitors with Diesel engines, 277; difficulty of repairing Diesel engines; "Selandia"; reason for preferring two-stroke cycle marine engines, 278; dangers arising from use of petroleum, 279; acid-forming nature of vegetable oils, 280.

DIESEL OIL-ENGINE, *Paper* by H. S. Pursey, 281.—Advantages and disadvantages, 281.—Procedure in starting engine; thermo-dynamic efficiency, 282; oil per b.h.p. at different loads, 283.—Cost per B.T.U. sold, 284; low cost of repairs, 284; compression in cylinder should be constant; disadvantages of Diesel engine, 285.—Marine engines, 286; double-acting engines; test of 240 b.h.p. set, 287.—Costs at various Diesel engine stations, 288.

Discussion.—Wyness, J., Satisfactory working with Indian native labour, 289.—Dawson, T. S., Valve cleaning, 289; increase in cost of fuel; running costs, 290; comparison with gas-engines, 291.—Williams, G. S., Steam-engines and stand-by charges, 291; cost of repairs counterbalanced by cost of lubricating oil, 292.—Bagshawe, B. W., Prospects of gas-engine in India, 293; comparative costs of steam, Diesel, and gas plants, 294.—Everett, W. H., Oil-consumption per h.p.-hour for two-stroke and four-stroke engines, 295.—Dawson, T. S., Tests with old engines and comparison with electricity, 295.—Pursey, H. S., Cleaning of valves, 296; cost of labour; price of oil, 297.—Wyness, J., Thanks to author, 297.

DINNER, Anniversary, 315.

DIXON, W., Remarks on Examinations, 168.

DOCKER, F. D., Companionship of the Order of the Bath, 85.

DODD J., Memoir, 556.

DOLBY, E. R., Remarks on Turbine-Pump, 55.

DOMLEO, R. F., elected Graduate, 176.

DONALDSON, Sir H. F., K.C.B., Knight Commandership of the Order of the Bath, 85.—Remarks on illness of President, 81:—on Annual Report, 134, 142.—Moved adoption of Annual Report, 144.—Remarks on Examinations, 146, 149, 150, 157, 158, 160, 161, 163:—on decease of T. P. Reay, 173:—on illness of President, 173:—on Diesel Oil-Engine, 230:—on Alloys Research, 458.

DONKIN FUND, BRYAN. *See* Bryan Donkin Fund.

DOUGLASS, P. C. D., elected Associate Member, 312.

DOVER, H. J., elected Associate Member, 3.

DRYDEN, A., Honorary Secretary of Calcutta and District Section, 93.—*Calcutta Section Paper* on Description of His Majesty's Mint, Calcutta, 93.

DURALUMIN, 449, 482, 499, 500–4. *See* Alloys Research.

EARNSHAW, W., elected Associate Member, 175.

ELECTION, Council, 82.—Members, 3, 174, 311.

ELLINGTON, E. B., Remarks on decease of S. W. Johnson, 1.—Nominated for re-election as President, 2.—Remarks on Turbine-Pump, 32.—Re-elected President, 82.—*Note* on Examinations, 131.—Remarks on Alloys Research, 445, 462, 480.

ENGERT, F. P., elected Associate Member, 312.

ENGINE, DIESEL OIL-, 179, 281. *See* Diesel Oil-Engine.

English, J., elected Graduate, 176.
Erith, C., Remarks on Diesel Oil-Engine, 260.
Everett, W. H., Remarks on Diesel Oil-Engine, 295.
Ewing, Sir J. A., Knight Commandership of the Order of the Bath, 85.
Examinations, 89, 124–133. *See* Council Annual Report.

Faulkner, J., elected Member, 3.
Fawcett, E. G. D., Remarks on Examinations, 171.
Fowler, H., Remarks on Alloys Research, 455.
Franklyn, F. E. H., elected Graduate, 176.
Fryer, J. E. G., Remarks on Examinations, 161.

Gale, T. J., elected Graduate, 176.
Gall, J., elected Member, 3.
Ganga Ram, Membership of the Royal Victorian Order, 85.
Gardner, A. C., Remarks on Examinations, 162.
Gas-Engine Research, 89.
Gass, W. G., elected Member, 311.
Gauvain, W. P., Associate Member transferred to Member, 5.
Gaze, E. H. J., Decease, 87.
Gimson, A. J., Decease, 87.
Goddard, H. P., elected Associate Member, 3.
Goldingham, A. H., elected Member, 3.
Goodwin, Eng. Capt. G. G., elected Member, 174.
Gore, G. E., Associate Member transferred to Member, 313.
Goslett, F. J., elected Member, 3.
Graduates, Invitations to attend Meetings of University Engineering Societies, etc., 93.
Graduates' Lectures, 71, 93. *See* Researches at National Physical Laboratory. *Lecture* on Wireless Telegraphy, by Capt. H. R. Sankey, 93.
Graduates' Papers, 93.
Graduates' Prizes, Award, 82.
Graham, A. J. W., elected Member, 311.
Graham, R. F., Remarks on Alloys Research, 478.
Grandage, N. A., elected Associate Member, 3.
Gray, A., elected Associate Member, 3.
Green, F. M., elected Graduate, 4.
Greenhill, T. A., Decease, 87.
Greenshields, C. D., elected Associate Member, 3.
Gregory, H. H., elected Associate Member, 312.
Griffith, P., Remarks on Examinations, 172.
Gurmin, E. W., elected Associate Member, 312.
Gwynne, J., Memoir, 557.

HADFIELD, Sir R. A., Remarks on Alloys Research, 497.
HALL, A. H., Remarks on Examinations, 168.
HALLETT, J. H., Decease, 87.
HAMBLY, P. N., Associate Member transferred to Member, 177.
HARBORD, F. W., Remarks on Alloys Research, 472, 474.
HARBOTTLE, J., elected Member, 3.
HARDING, W. A. D., elected Member, 174.
HARDISTY, J., elected Member, 3.
HARFIELD, W. H., Decease, 87.
HARRIS, A. E., *Graduates' Paper* on Recent Improvements in Wood-working Machinery, 93.
HARRISON, D. R. D., elected Associate Member, 312.
HARRISON, N., Memoir, 557.
HARRISON, W. G., elected Associate Member, 312.
HARROP, F. H., elected Member, 174.
HASENDAHL, W., elected Associate Member, 3.
HAWKINS, H. C., elected Associate Member, 175.
HEALD, J. A., Decease, 87.
HEAP, W., Decease, 87.
HELE-SHAW, H. S., Remarks on Examinations, 161.
HENDERSON, P., Associate Member transferred to Member, 5.
HENRIQUES, P. Q., elected Associate Member, 3.
HERON, S. D., elected Graduate, 4.
HICKLING, F., elected Graduate, 176.
HILL, J. A., elected Member, 174.
HINCKS, J. M., Decease, 87.
HINDE, W. J., elected Associate Member, 175.
HIPKINS, W. E., Memoir, 558.
HODGSON, C., Memoir, 558.
HOLMES, R. B. W., Associate Member transferred to Member, 313.
HONOURS conferred upon members, 85.
HOPKINSON, E., *Paper* on the Evolution of the Turbine-Pump, 7.—Remarks thereon, 32, 58, 68.
HORN, B., elected Associate Member, 175.
HOUSTON, P. T., Remarks on Diesel Oil-Engine, 262.
HOW, T. W., elected Member, 174.
HOWARD, P., elected Associate Member, 3.
HOWE, H. B., Memoir, 559.
HOWLDEN, E. F., Decease, 87.
HUBBACK, C. A., Decease, 87.
HUDDLESTON, G. R. G., elected Associate Member, 175.
HUNTER, C. F., Remarks on Examinations, 152.

HUNTINGTON, A. K., Remarks on Alloys Research, 452, 454.
HUTSON, C. A., elected Associate Member, 175.

IDDON, J., Decease, 87.
ILLINGWORTH, H. S., elected Graduate, 313.
INGHAM, E., elected Associate Member, 175.
INSTITUTION BUILDING EXTENSIONS, 88.
INSTITUTION DINNER, 315.
INTERNAL-COMBUSTION ENGINES, Measurement of Air-Supply, 517. *See* Air-Supply to Internal-Combustion Engines.
ISAAC, M. T., elected Associate Member, 175.

JACKSON, J. W., Associate Member transferred to Member, 177.
JANUARY MEETING, 1912, Business, 1.
JEFFERISS, H. E., elected Associate Member, 175.
JENKINS, W. J., Decease, 87.
JOHNSON, S. W., Decease, 1.—Memoir, 302.
JOHNSTON, A. D., JUN., elected Associate Member, 312.
JONES, F. M., elected Member, 174.
JOY, B. H., Remarks on Diesel Oil-Engine, 243.
JULIUS, G. A., elected Member, 311.
JUPP, W. D. L., elected Associate Member, 312.

KEEN, A., Retirement from Vice-Presidency, 2, 94.
KEMPE, H. R., elected Member, 174.
KEMPE, I. T., elected Graduate, 313.
KENDAL, A. B., elected Associate Member, 175.
KENDALL, A. H., elected Associate Member, 175.
KENNEDY, A. V., elected Associate Member, 312.
KENT-NORRIS, H., JUN., elected Associate Member, 175.
KERR, R. P., elected Associate Member, 3.
KERSHAW, J., Memoir, 304.
KIBBLER, H., elected Associate Member, 312.
KIDD, F., elected Member, 174.
KING, T. S., Decease, 87.
KIRBY, J. P., elected Associate Member, 4.
KIRKWOOD, J. E., elected Member, 174.
KITCHING, A., Decease, 87.
KNOWLES, L., Associate Member transferred to Member, 177.
KOHLER, F., elected Associate Member, 312.
KOZIELL, Eng. Capt. J. P., Decease, 87.

Lambert, J. H., Associate Member transferred to Member, 177.
Landstein, W., Decease, 87.
Lantsberry, F. C. A. H., Remarks on Alloys Research, 498.
Lauder, R. B. D., elected Graduate, 176.
Law, E. F., Remarks on Alloys Research, 476, 477.
Lawes, G. E., Memoir, 305.
Lawton, H. A., elected Graduate, 313.
Lectures on Steel, 92.
Leek, A. E., elected Associate Member, 175.
Le Pla, F. G. R., elected Associate Member, 175.
Lewis, Sir W. T., Barony, 85. *See* Merthyr, Lord.
Library, Donations and Purchases, 90, 105–123.
Linley, P., elected Graduate, 313.
Lister, Eng. Com. F. H., elected Member, 174.
Littledale, E. H., elected Graduate, 313.
Livsey, H., elected Member, 174.
Loan of Meeting Hall, etc. *See* Rooms, Loan of.
Loving, H. C., elected Member, 312.
Lydall, C. H., elected Associate Member, 175.

McCallum, W. A., elected Associate Member, 4.
McCarthy-Jones, C., *Calcutta Section Paper* on The Curtis Steam-Turbine, 93.
McCowen, V. A. H., Decease, 87.
Macdonald, F. C., Memoir, 306.
McFee, W. M. P., elected Associate Member, 175.
McGregor, J., Decease, 87.
MacIntyre, N., elected Member, 312.
McKechnie, J., Remarks on Alloys Research, 500.
Mackenzie, G. S., elected Associate Member, 4.
McLaren, R., elected Member, 3.
McLean, R. A., reappointed to audit Institution Accounts, 84.
McNeil, W., elected Member, 3.
McPherson, S., Memoir, 307.
McQuaigue, F. E., elected Graduate, 176.
Mair, G. P., Remarks on Turbine-Pump, 51.
Manico, E. L., elected Graduate, 176.
Mansell, L. T. G., elected Graduate, 313.
March Meeting, 1912, Business, 173.
Marks, E. C. R., Remarks on Annual Report, 139:—on Examinations, 164.
Marks, Sir G. C., Knighthood, 85.
Mason, H. R., elected Associate Member, 175.
Mason, J. W., elected Graduate, 176.

MATTHEWS, T. B., Memoir, 560.
MATTHEWS, W. E., Associate Member transferred to Member, 313.
MAW, A. E., elected Associate Member, 312.
MAW, W. H., Seconded adoption of Annual Report, 144.
MAY MEETING, 1912, Business, 318.
MEETINGS, 1912, January, 1.—Annual General, 81.—March, 173.—April, 311.—May, 318.
MEMBERS, etc., Roll, 86.
MEMOIRS of Members recently deceased, 299, 553.
MENEZES, A. G. DE, elected Associate Member, 312.
MERTHYR, Lord, K.C.V.O., re-elected Vice-President, 82.—Creation of Peerage, 85.
METCALFE, H. F., elected Member, 3.
MIDDLETON, R. T., Decease, 87.—Memoir, 307.
MILLINGTON, W. E. W., Remarks on Turbine-Pump, 37.
MILLS, J. A., Associate Member transferred to Member, 82.
MILLS, W., Remarks on Alloys Research, 467.
MILWARD, W. F., elected Associate Member, 175.
MINNITT, J. A., elected Associate Member, 4.
MOIR, W. R., elected Associate Member, 4.
MONTGOMERY, C. H., Associate Member transferred to Member, 177.
MOORE, E. S., elected Associate Member, 175.
MOORE, J. L. M., elected Graduate, 176.
MOORE, W. G., elected Member, 174.
MORGAN, C. H., Decease, 87.
MORGAN, W. H., elected Associate Member, 4.
MORISON, D. B., nominated for election as Member of Council, 2.—Appointed Member of Council, 173.
MORRIS, F. S., Decease, 87.
MORRISON, W. M., Remarks on Alloys Research, 454.
MOSS, F. C., elected Associate Member, 312.
MUNTZ, Sir G. A., Bart., Remarks on Alloys Research, 449.
MURRAY, W. R., elected Associate Member, 175.
MYERS, A. C. T., elected Associate Member, 175.

NATIONAL PHYSICAL LABORATORY, Teddington, Recent Researches, 71. *See* Researches at National Physical Laboratory.
NEILSON, A. McN., elected Graduate, 176.
NISBET, J. W., Decease, 87.
NORRIS, R., elected Graduate, 313.
NORRIS, W. G., Decease, 87.—Memoir, 308.
NUNN, H. V., elected Associate Member, 175.

Oil-Engine, Diesel, 179, 281. *See* Diesel Oil-Engine.
Okey, W. E., elected Graduate, 4.
Oxley, J. H. W., elected Associate Member, 4.

Pannell, J. R., elected Associate Member, 312.
Parsons, J., elected Associate Member, 312.
Parsons, The Hon. R. C., Remarks on Turbine-Pump, 61.
Patchell, W. H., Remarks on Turbine-Pump, 46.—Appointed Member of Council, 174.—Remarks on Alloys Research, 486, 487.
Peace, A. G., elected Graduate, 176.
Pendred, L., Remarks on Alloys Research, 463.
Penwarden, C. W. H., elected Member, 312.
Pirrie, Lord, K.P., P.C., nominated for election as Member of Council, 2.—Re-elected Member of Council, 82.
Pitkeathly, J. S., Companionship of the Royal Victorian Order, 85.
Pitt, R. B., elected Graduate, 4.
Pitt, W., re-elected Member of Council, 82.
Pollard, H., elected Graduate, 313.
Pooley, J. P. F., elected Associate Member, 4.
Potts, S., elected Associate Member, 312.
Preedy, C. H., elected Graduate, 4.
Price, F. L., elected Associate Member, 175.
Price, O. A., Remarks on Turbine-Pump, 63.—Elected Associate Member, 312.
Price, W. J., elected Associate Member, 4.
Pritchard, W. E., Remarks on Examinations, 169.
Pump, Evolution of the Turbine-, 7. *See* Turbine-Pump.
Pursey, H. S., *Paper* on Diesel Oil-Engine, 281.—Remarks thereon, 296.

Rabines, M. A., elected Graduate, 4.
Raworth, B. A., Remarks on Examinations, 148, 149, 150.
Reay, T. P., Decease, 173.—Memoir, 308.
Redding, F. C., elected Associate Member, 312.
Reeve, R. J. R., Associate Member transferred to Member, 177.
Report of Council, Annual, 85. *See* Council, Annual Report.
Representatives, Institution, 90.
Research, Alloys, 89:—Gas-Engines, 89:—Subjects for, 89.
Researches at National Physical Laboratory, *Lecture* by T. E. Stanton to the Graduates, 71.—Distribution of wind pressure on circular plate, 72.—Formation of eddies at back of plate, 73.—Distribution of pressure on plates inclined to the wind, 75.—Normal pressure on plates inclined to direction of current, 75.—Lift and drift curves, 75.—Comparison of pressure on flat plate and on aerofoil, 76.—Aerofoil

more efficient than flat plate at angles above 5½°, 77.—Propellers, 77; Drzwiecki's method of propeller design, 78.

RESIGNATIONS OF MEMBERSHIP, 86.

REYNOLDS, J., Decease, 87.

RHODES, W. F., elected Associate Member, 4.

RICHARDS, W. J., elected Associate Member, 4.

RICHARDSON, E. L., elected Member, 3.

RICHES, T. H., Decease, 87.

RIDDELL, H., elected Member, 312.

RIELLY, P., elected Associate Member, 312.

RIES, A. H., elected Associate Member, 312.

ROBB, H. B., elected Graduate, 176.

ROBERTS, D. E., Remarks on Annual Report, 145.

ROBERTS, H. J., Associate Member transferred to Member, 177.

ROBERTSON, C. E., elected Graduate, 4.

ROBINSON, A. E., elected Associate Member, 4.

ROBINSON, C. J., elected Graduate, 176.

ROBINSON, M., re-elected Member of Council, 82.—Remarks on Diesel Oil-Engine, 248.

ROBINSON, P. M., elected Associate Member, 4.

ROMANS, A. H., elected Associate Member, 312.

ROOMS, LOAN OF, to kindred Societies, 90.

ROSENHAIN, W., *Tenth Report* to the Alloys Research Committee: On the Alloys of Aluminium and Zinc, 319.—Remarks thereon, 454, 457, 467, 474, 477, 481, 486, 487, 511.

ROWE, P., Decease, 87.

ROWELL, H. S., elected Associate Member, 313.

ROYDS, R., Remarks on Examinations, 169.

RUSCOE, J. O., elected Graduate, 4.

RUSSELL, H. S., Remarks on Diesel Oil-Engine, 249.

SALTER, J. R., Decease, 87.

SAMS, J. H., Remarks on Examinations, 169.

SANKEY, Capt. H. R., *Lecture* to Graduates on Wireless Telegraphy, 93.—Remarks on Alloys Research, 478.

SARGENT, T., elected Associate Member, 313.

SAYER, A. E., elected Member, 174.

SCHOFIELD, H., *Paper* on the Measurement of the Air-Supply to Internal-Combustion Engines, by means of a Throttle-Plate, 517.

SCHUBELER, J. F., Remarks on Turbine-Pump, 41.

SCHULTZ, G. C., elected Associate Member, 176.

SCOTCHER, W. G., elected Graduate, 313.

SCOTT, Sir W., Bart., Decease, 87.
SELFE, N., Decease, 87.
SELIGMAN, R., Remarks on Alloys Research, 504.
SHAW, W. M., elected Associate Member, 4.
SIDAHMED, M. S., elected Graduate, 4.
SINCLAIR, H., elected Associate Member, 4.
SINGLETON, S. M., elected Associate Member, 4.
SMITH, E. T., Associate Member transferred to Member, 313.
SMITH, H. E., elected Associate Member, 4.
SMITH, S. A., Remarks on Examinations, 156, 158, 160, 161.
SOUTER-ROBERTSON, D., Memoir, 309.
SPINK, R. J., elected Graduate, 4.
SPOONER, G. P., Remarks on Examinations, 155.
SPRING, Hon. Sir F. J. E., Knight Commandership of the Order of the Indian Empire, 85.
STANTON, T. E., *Lecture* to Graduates on Recent Researches at the National Physical Laboratory, Teddington, 71.
STARLEY PREMIUM FUND, Accounts, 101.—Regulations for Second Award, 104.
STEEL, *Lectures* by W. Rosenhain, 92.
STEPHENSON, A. H., elected Member, 175.
STEWART, J. C., elected Graduate, 5.
STRACHAN, J. A. P., elected Associate Member, 176.
SUMMER MEETING, Zürich, 1911, 91.
SUMNER, L., Remarks on Alloys Research, 508.
SUTTON, J. W., Moved reappointment of Auditor, 84.
SWINBURNE, M. W., Memoir, 560.

TAUNTON, R. H., Decease, 87.
TAYLOR, W. I., Decease, 87.
TAYLOR, W. R. C., Decease, 87.
TAYLOR, W. T., elected Associate Member, 176.
TEED, Eng. Com. H. R., elected Member, 175.
TEMPLE, G. L., elected Graduate, 176.
THOMPSON, A. E., elected Associate Member, 313.
THOMPSON, G. W., Seconded reappointment of Auditor, 84.
THORNE, D. S., elected Associate Member, 176.
THORPE, H. T. E., elected Associate Member, 313.
TIBBENHAM, L. J., elected Associate Member, 4.
TIMOTHY, E., *Graduates' Paper* on Foundry Plant, Machinery and Working, 93.
TOMPKINS, Eng. Com. A. E., Remarks on Examinations, 171.
TRANSFERENCES of Associate Members to Members, 5, 82, 177, 313.

TROUGHTON, H. J., elected Associate Member, 176.

TUNLEY, P. J., Decease, 87.

TURBINE-PUMP, *Paper* on the Evolution and present development of the Turbine-Pump, by E. Hopkinson and A. E. L. Chorlton, 7.—Rotary engine supersedes reciprocating engine, 7 ; Papin's centrifugal pump ; John Gwynne's series centrifugal pump, 8.—Reynolds' turbine-pump of 1875 ; Mather and Platt's pump of 1887, 10 ; its commercial manufacture in 1893, 11 ; form of impeller and delivery-casing, 12.—Curves showing relative velocity through impellers, 13.—Comparison of results with different impellers, 14.—Guide-vanes, 15.—Efficiencies of an 1895 pump and modern pump, 15.—Importance of long divergent guide-channels, 16.—Effect of different forms of guide-passages and return-passages, 18.—Sulzer Brothers' four-chamber high-lift centrifugal pump, 19 ; Mather and Platt's four-chamber pump, 22.—Installations : Bore-hole pump of 1897, 23 ; Sulzer mine-pump of 1898 ; Cambridge University Laboratory pump ; Newcastle electric power station plant, 25 ; Mine-drainage pump of 1911, 26 ; Boiler feed-pump of 1909, 27 ; Fire-pumps, 29 ; waterworks pump driven by steam-turbine, 30.

Discussion.—Ellington, E. B., Thanks to authors, 32.—Hopkinson, E., History of centrifugal pumps, 32 ; Hon. R. C. Parsons' experiments ; confirmed by Dr. Unwin ; effect of guide-vanes, 33.—Unwin, W. C., Efficiency of centrifugal pumps on low heads ; early series pumps, 34 ; pumps and motors are reciprocal machines ; Thomson's vortex turbine ; loss of kinetic energy of discharge, 35 ; largest centrifugal pump driven by Corliss engine, 36.—Millington, W. E. W., Comparative costs of centrifugal and reciprocating pumps, 37 ; difficulty of balancing end-thrust on impellers ; balancing arrangement, 38 ; four-stage centrifugal pump ; self-regulation, 40.—Schubeler, J. F., Johnson's three-stage centrifugal pump of 1846, 42 ; Reynolds' guide-vanes ; characteristics of modern turbine-pump, 43 ; early pumps of Sulzer Brothers ; application of electricity for pump driving, 44 ; influence of impeller-vanes ; methods of overcoming axial thrust, 45.—Patchell, W. H., Reliability of turbine-pump, 46 ; particulars of Sulzer pumping equipment in South Wales, 48 ; efficiency therefrom, 49.—Allen, R. W., Effect of shrouded disk ; position of pump bearings ; corrosion of impellers, 50.—Mair, G. P., Pumps with surface-condensers ; balancing arrangement, 51 ; removal of end-thrust, 52.—Atherton, W. H., Increase of head obtainable in modern pumps, 52 ; multiple pumps in series, 53 ; omission of vortex chambers ; reaction impellers, 54.—Dolby, E. R., Turbine-pumps for reinforced circulation, 55.—Chorlton, A. E. L., Scope of Paper, 55 ; balance devices ; early American series-pump, 56 ; bronze wheels ; back-to-back arrangement of impellers, 57 ; reaction impellers; gauges for reading differential head between two sides of pump, 58.—Hopkinson, E., Terminology, 58; three classes of centrifugal pumps, 59.

Communications.—Attack, A. M., Relative velocities through impellers, 60; speed of boiler feed-pump, 61.—Parsons, Hon. R. C., Laws governing principle and design of centrifugal pumps enunciated in 1875, 61.—Price, O. A., Irregularities in curves of tests, 63; effect of aeration on pump, 64; experiments of single impeller with different guide-vanes, 65; self-regulation or power limitation, 67.—Wilkinson, G., Electrical energy required for turbine-pump as compared with three-throw reciprocating pump, 67.—THE AUTHORS, Velocities through impellers, 68; experiments made to show effect of different guide- and return-passages, 69.

TURNBULL, W. L., Decease, 87.

TYRRELL, J., elected Member, 312.

UNWIN, W. C., nominated for election as Vice-President, 2.—Remarks on Turbine-Pump, 34.—Elected Vice-President, 82.

VENTRESS, E. W. S., elected Associate Member, 4.

VINCE, J. S., elected Graduate, 313.

WAINWRIGHT, J. W., Remarks on Examinations, 155:—on Diesel Oil-Engine, 266.

WAKE, H. H., Decease, 87.

WALKER, F. H., elected Associate Member, 4.

WALKER, N. H., elected Graduate, 5.

WALPOLE, T., Decease, 87.

WARDLE, G. E., elected Graduate, 176.

WATER ARBITRATION PRIZE FUND, Accounts, 100.—Regulations for Third Award, 102.

WATSON, G. W., Associate Member transferred to Member, 177.

WATSON, H. A., elected Associate Member, 176.

WATSON, J., Decease, 87.

WATSON, W., *Paper* on The Measurement of the Air-Supply to Internal-Combustion Engines, by means of a Throttle-Plate, 517.

WATTS, J., Decease, 87.

WEBB, H. A., elected Associate Member, 176.

WEBBER, W., elected Member, 3.

WEBSTER, F. T., Decease, 87.

WHITAKER, A., elected Associate Member, 4.

WHITAKER, P. H., elected Associate Member, 313.

White, Sir W. H., K.C.B., Remarks on Alloys Research, 445, 455.
Whitehead, R., elected Graduate, 313.
Whitelegg, S. H., elected Associate Member, 313.
Wickham, O., *Graduates' Paper* on The Application of Liquid Fuel to the Industries, 93.
Wilkinson, G., Remarks on Turbine-Pump, 67.
Wilkinson, L. M., elected Member, 312.
Willans Premium Fund, Accounts, 100.
Willcox, R. J. N., Remarks on Diesel Oil-Engine, 269.
Williams, G. S., Remarks on Diesel Oil-Engine, 291.
Willis, Capt. G. H., Membership of the Royal Victorian Order, 85.
Wilson, A. H., elected Graduate, 313.
Wilson, C., elected Member, 312.
Wilson, J., elected Graduate, 5.
Wilson, J. V., Remarks on Diesel Oil-Engine, 273.
Wilson, R. D., Associate Member transferred to Member, 5.
Wingfield, C. H., Remarks on Alloys Research, 508.
Winmill, G., Decease, 87.
Wireless Telegraphy, *Lecture* to Graduates by Capt. H. R. Sankey, 9 .
Womersley, W. D., elected Graduate, 5.
Wood, W. C., Memoir, 561.
Woodfield, C. H., elected Associate Member, 313.
Woodward, R., elected Graduate, 5.
Worsdell, W., re-elected Member of Council, 82.
Wright, W. R., Decease, 87.
Wyness, J., Chairman of Calcutta and District Section, 1911, 93.—Remarks on Diesel Oil-Engine, 289, 297.

Yates, R. C. C., elected Associate Member, 176.

Zinc-Aluminium Alloys, 319. *See* Alloys Research, *Tenth Report*.
Zolmer, W. V., elected Graduate, 5.
Zürich Summer Meeting, 1911, 91.

Fig. 4. *Impeller and Guide-Passages, 1895. (Mather-Reynolds.)*

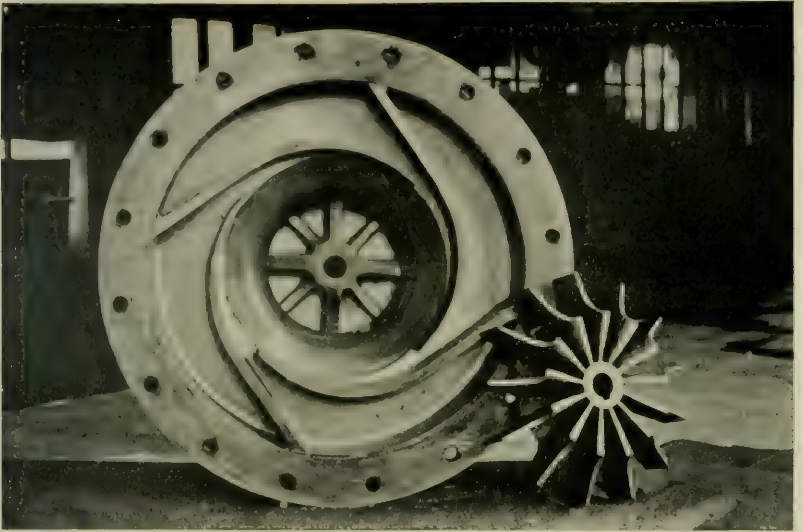


Fig. 8. *Guide-Vanes of 1895 Pump (Mather-Reynolds) and Modern Pump.*

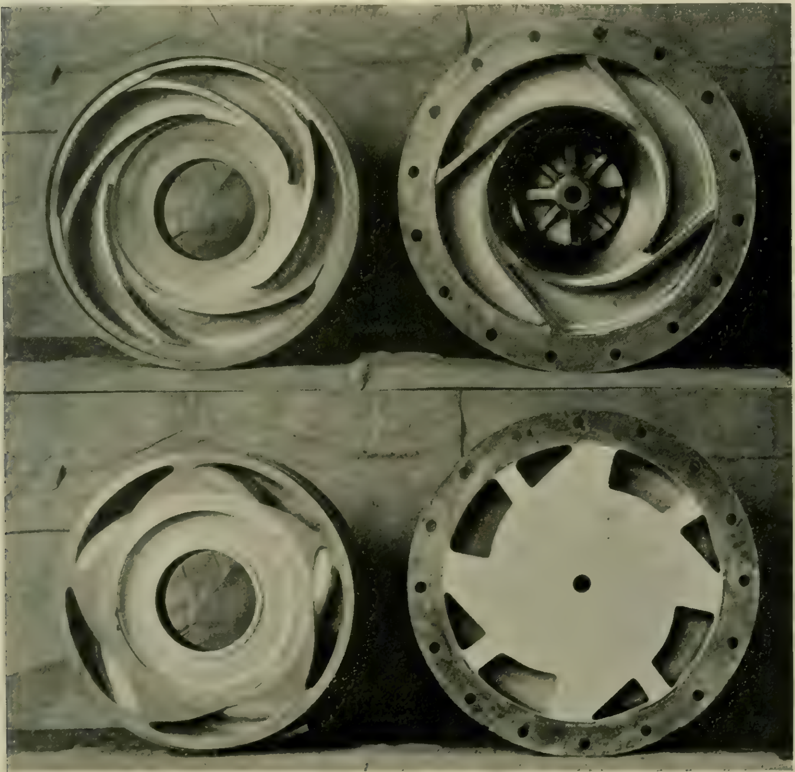


Fig. 11. *Short and Long Guide-Passages.*
See Curves A and B, Fig. 10.

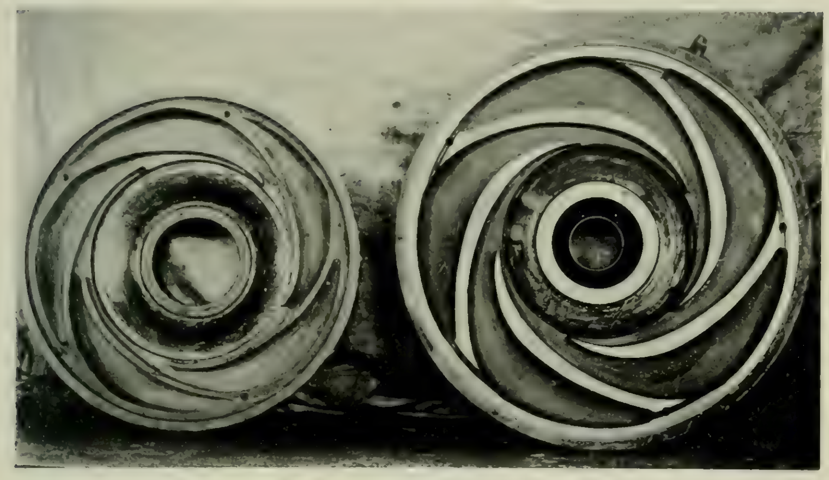


Fig. 16. *Impeller of Modern Four-chamber Pump.* *(Mather and Platt.)*

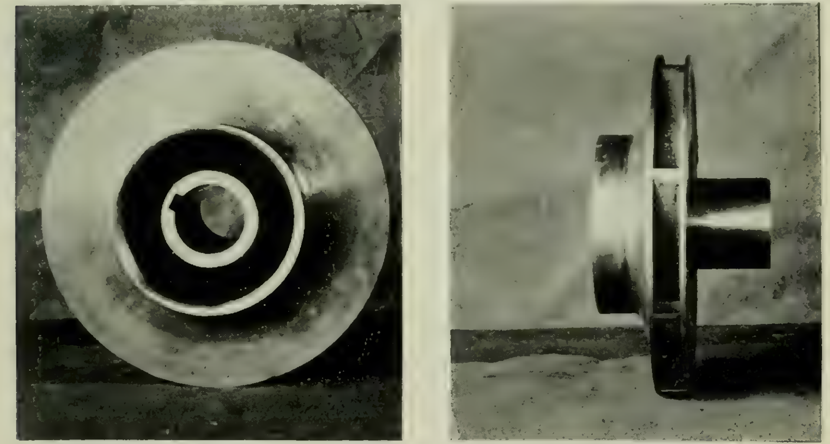
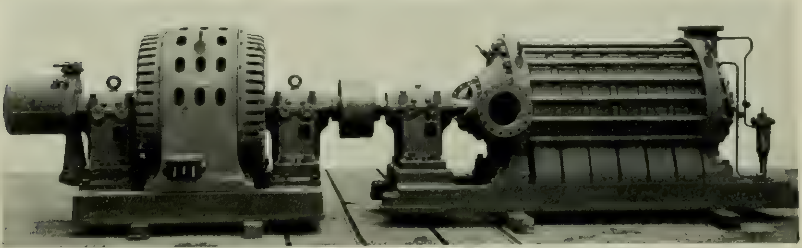
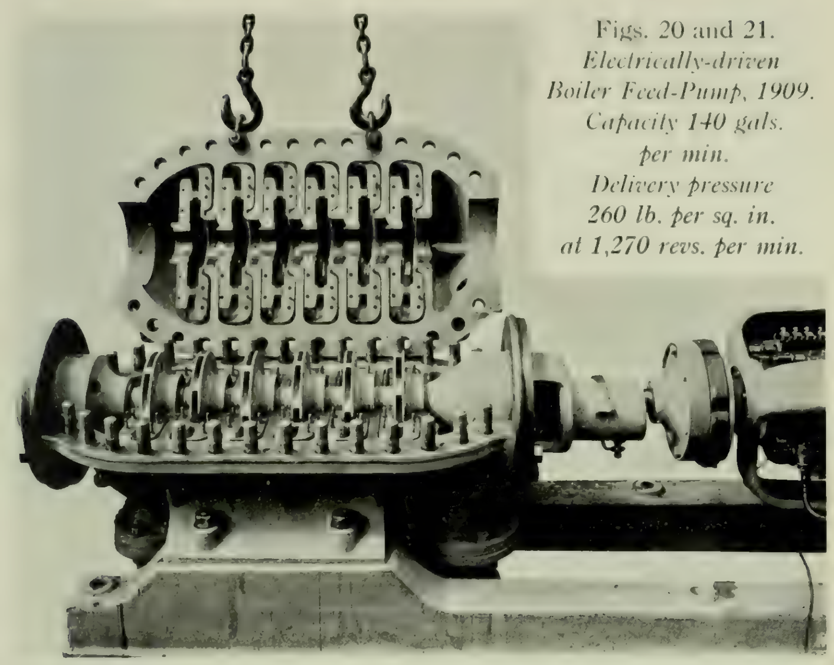
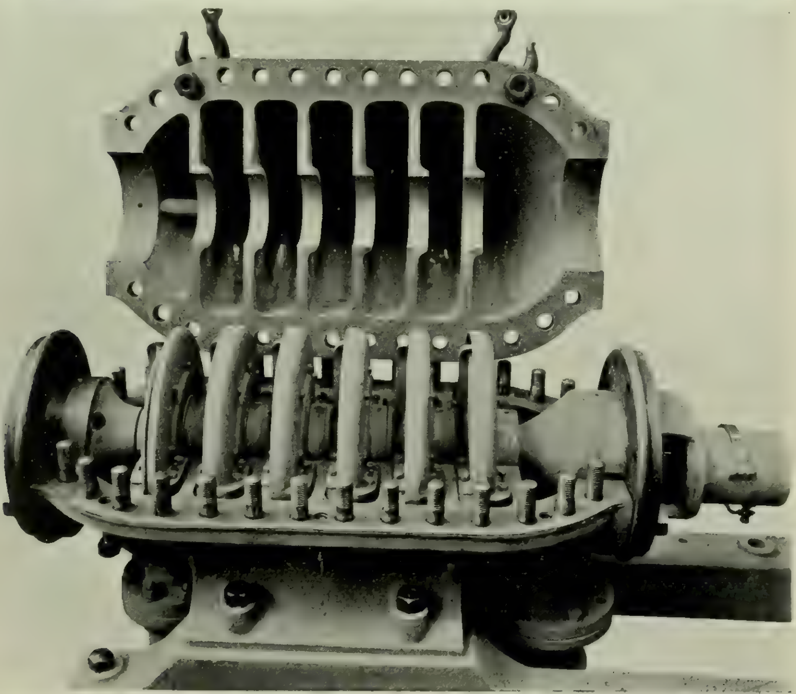


Fig. 19. *Mine-Drainage Pump, 1911.*







Figs. 20 and 21.
Electrically-driven Boiler Feed-Pump, 1909.
Capacity 140 gals. per min.
Delivery pressure 260 lb. per sq. in. at 1,270 revs. per min.

Pl. 4.

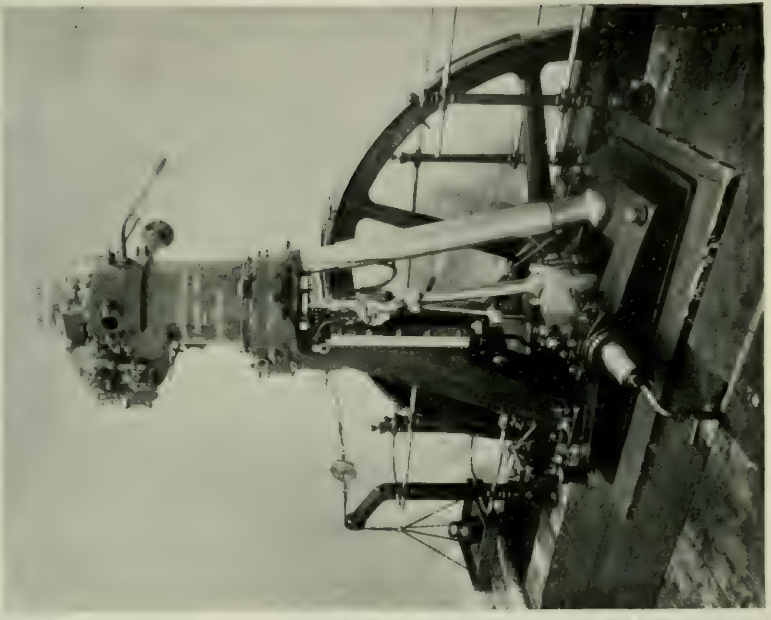


Fig. 9. *First Complete Engine, 18 H.P., 1897.*
Showing brake and other testing apparatus.

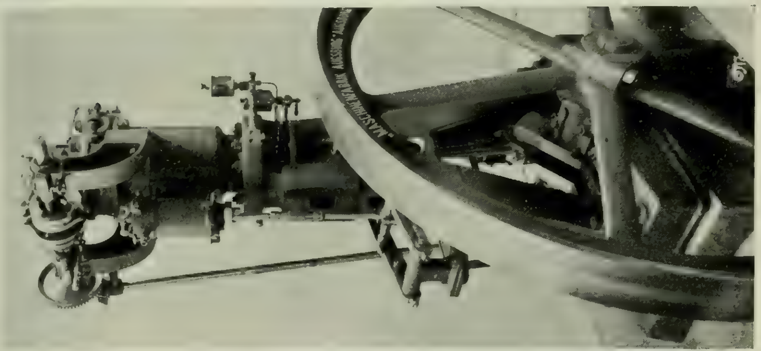


Fig. 8. *Later Experimental Pattern, 1895-96.*

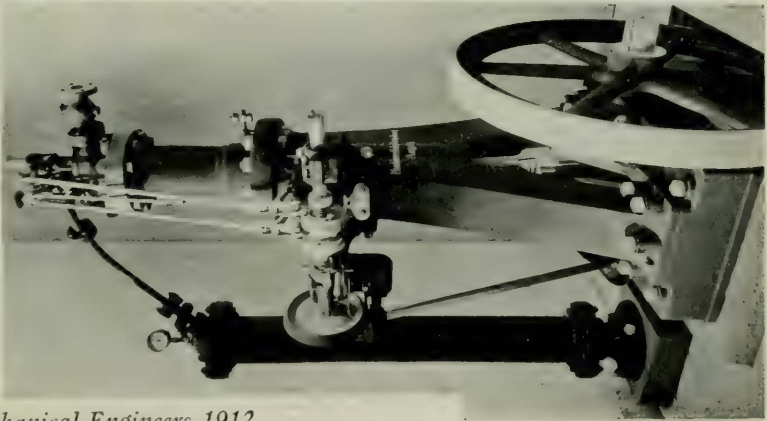


Fig. 7. *First Experimental Diesel Engine, 1893.*

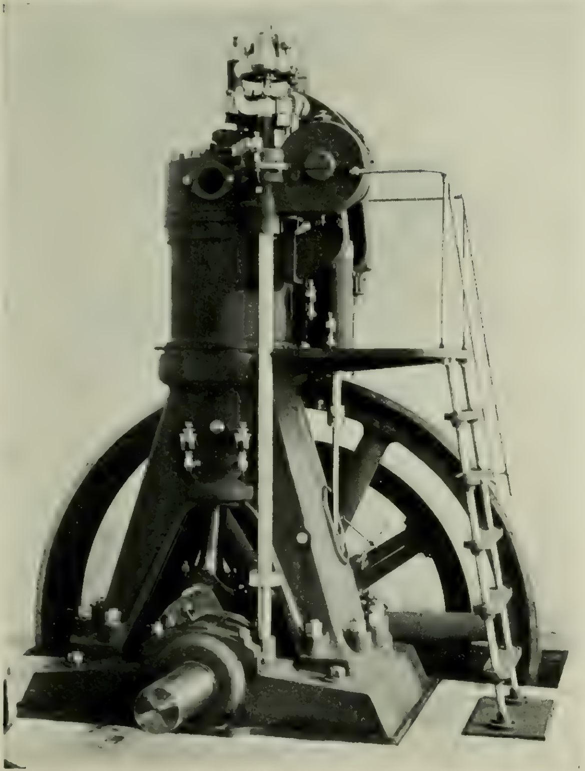


Fig. 10. *Trunk Piston Type. 70 to 90 H.P. 1901.*
Cyl. 15·75 inch diam. 26·62 inch stroke. 150 r.p.m.

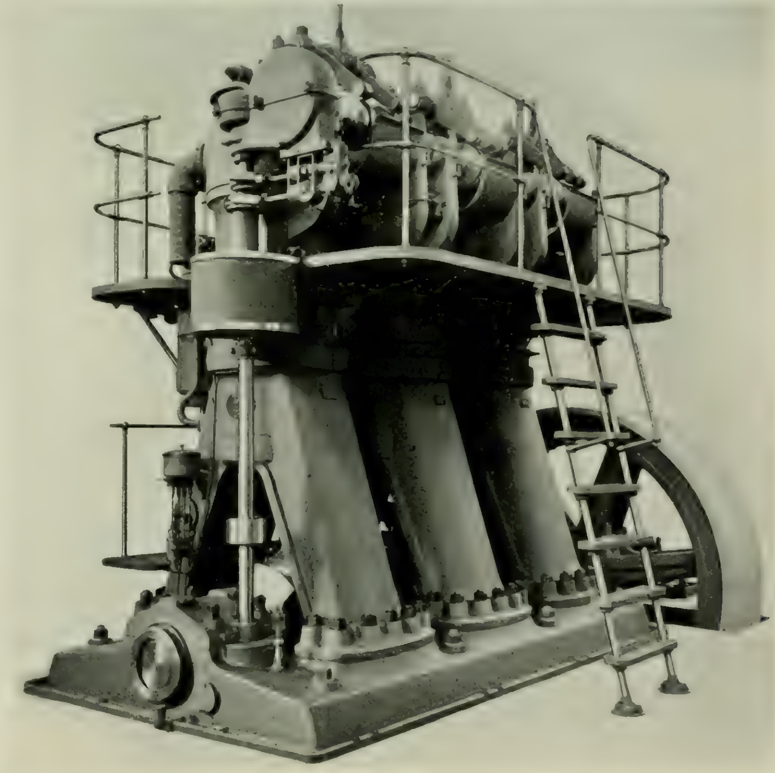


Fig. 11. *Three-cylinder 300 H.P. Engine. 1906.*

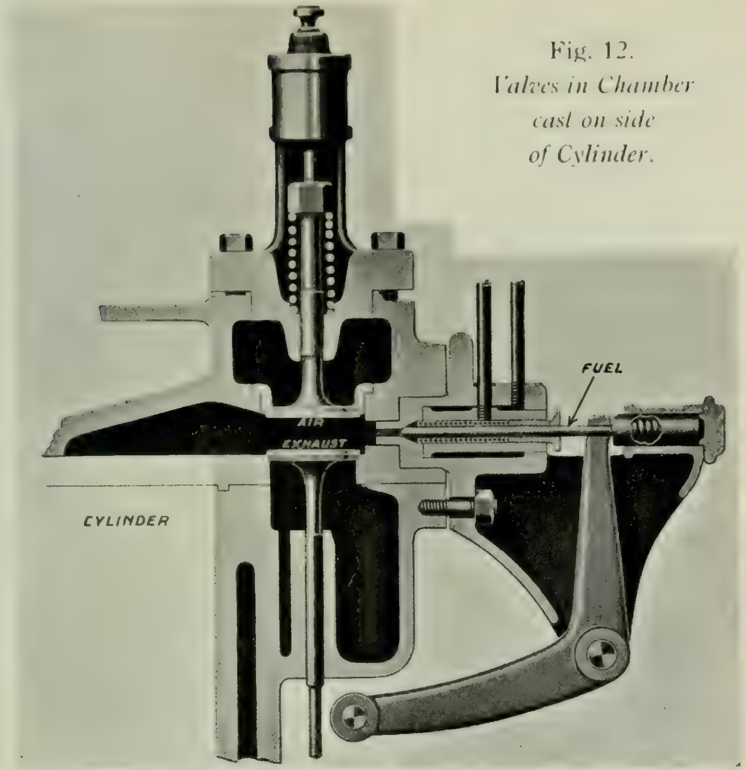
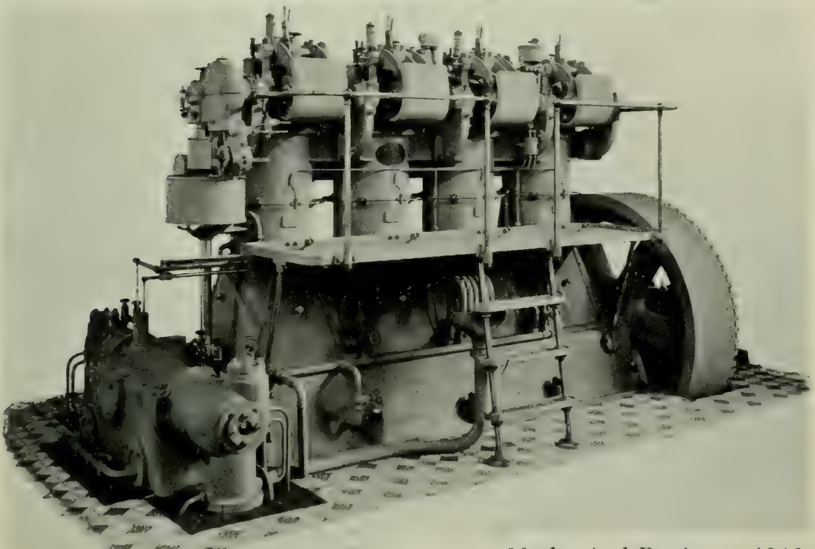


Fig. 12.
Valves in Chamber cast on side of Cylinder.

Fig. 13. *Four-stroke Cycle High-speed Engine, 1909. Showing Box-frame and Air-pump.*



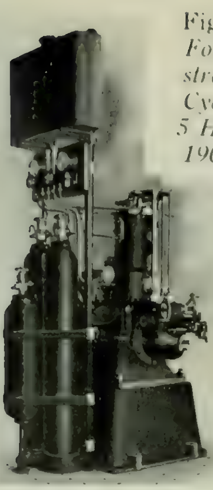


Fig. 14.
*Four-stroke Cycle.
5 H.P.
1909.*

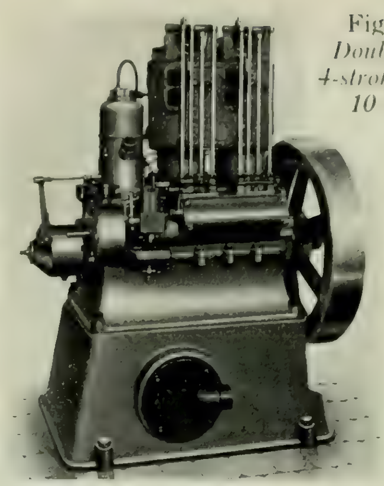


Fig. 15.
*Double cyl.
4-stroke Cycle.
10 H.P.*

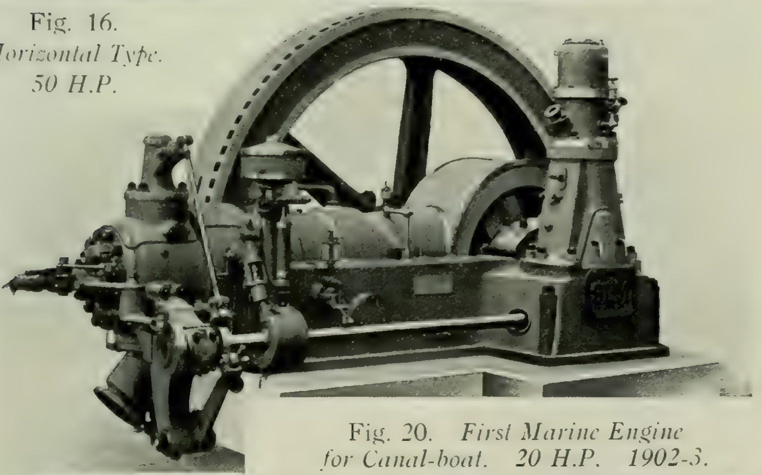
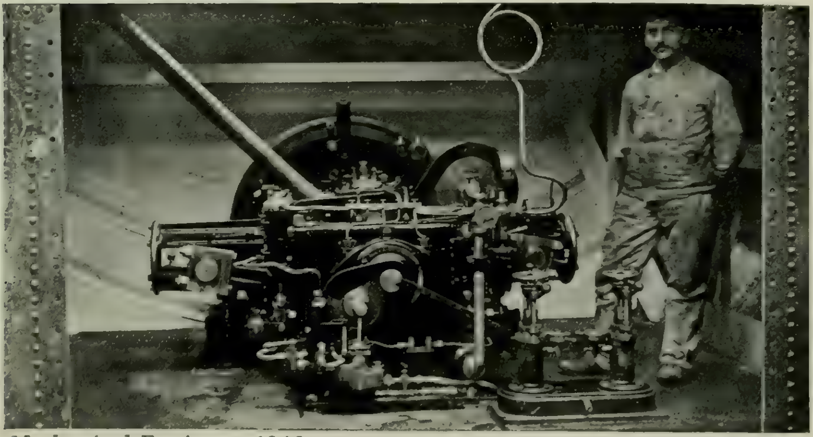


Fig. 16.
*Horizontal Type.
50 H.P.*

Fig. 20. *First Marine Engine for Canal-boat. 20 H.P. 1902-3.*



DIESEL OIL-ENGINE.

Plate 8.

Fig. 21. *Four-stroke Cycle Engine. 120 H.P. 1908.*

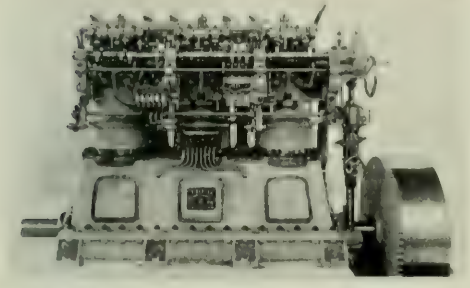


Fig. 22. *Experimental reversible 4-cyl. 4-stroke cycle. 30 H.P. 600 r.p.m. 1909.*

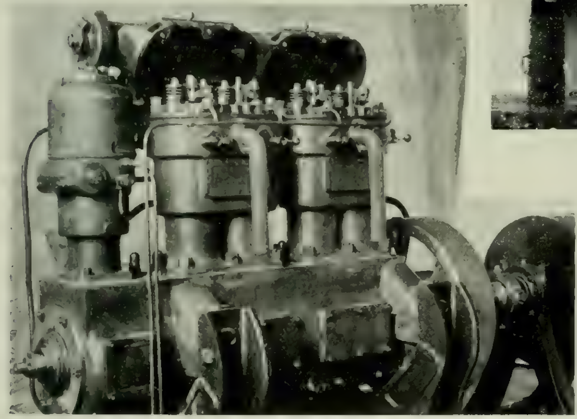


Fig. 23. *Six-cyl. Marine Engine. 300 r.p.m. 1911. Scavenging Valves below.*

Fig. 24. *Single-cyl., Single-acting Two-stroke Cycle. 1,200 H.P. 1911.*

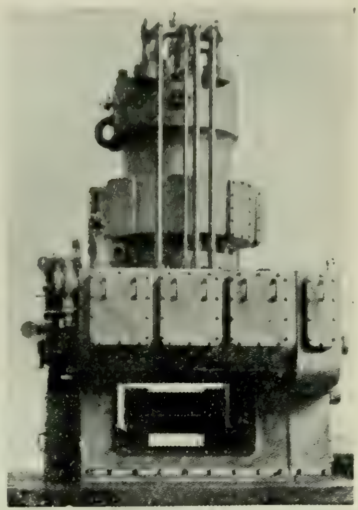
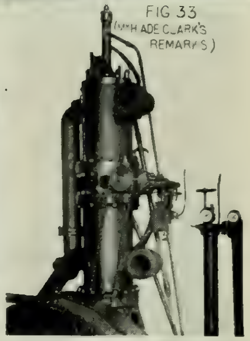


FIG 33
(MR H ADE CLARK'S
REMARKS)



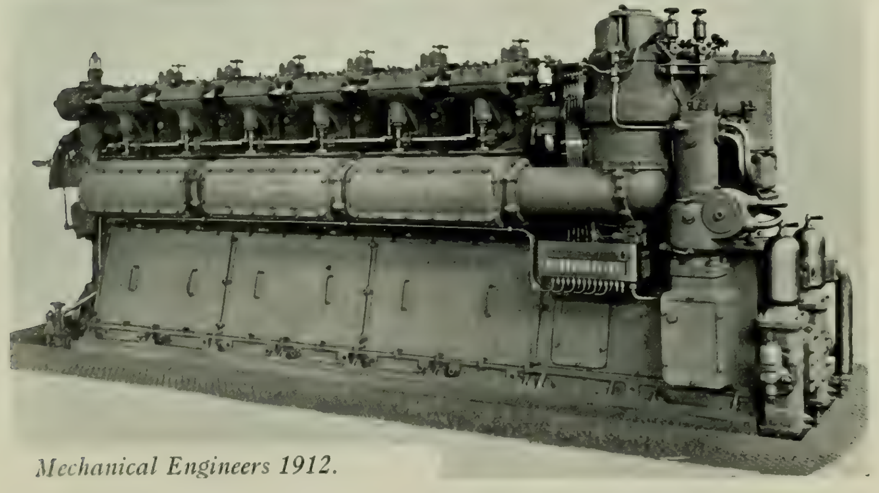


Fig. 2. *Crystal of Aluminium Zinc Compound.* × *200 diams.*

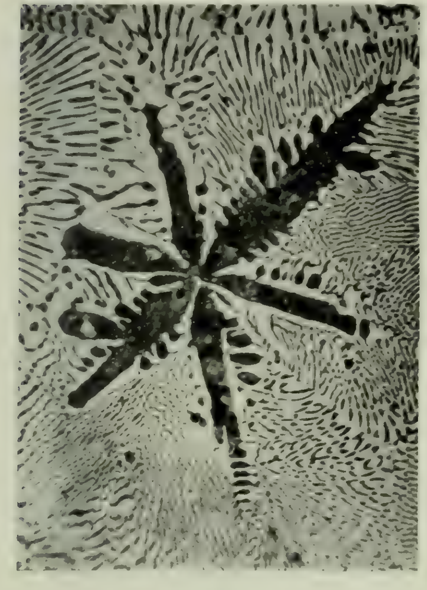


Fig. 3. *Alloy No. 77.* *77 % Zinc.* × *150 diams.*

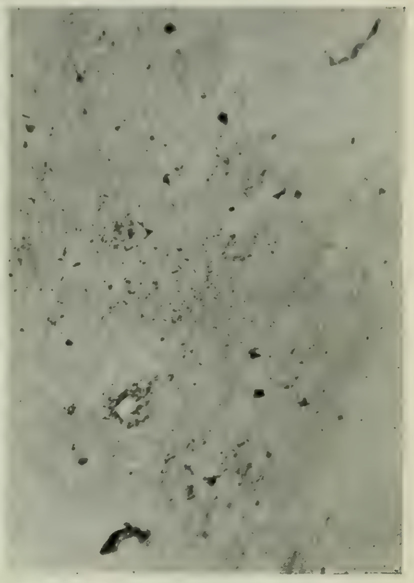


Fig. 4. *Alloy No. 77.* *77 % Zinc.* × *600 diams.*

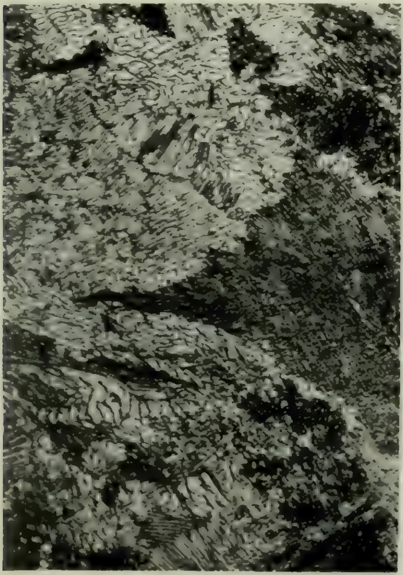


Fig. 5. *Alloy No. 84.* *84 % Zinc.* × *300 diams.*

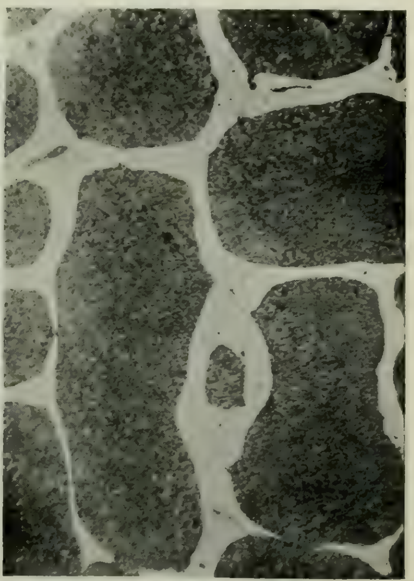


Fig. 6. *Alloy No. 84. 84% Zinc. × 300 diams.*

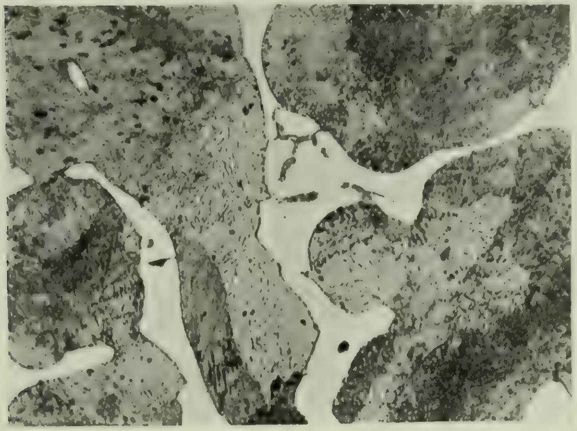


Fig. 7. *Alloy No. 70. 70% Zinc. × 150 diams.*

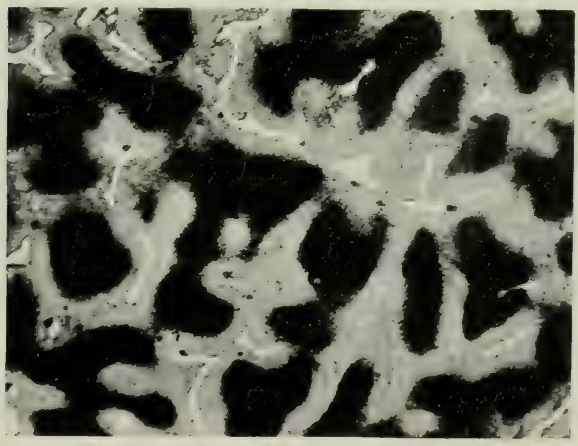
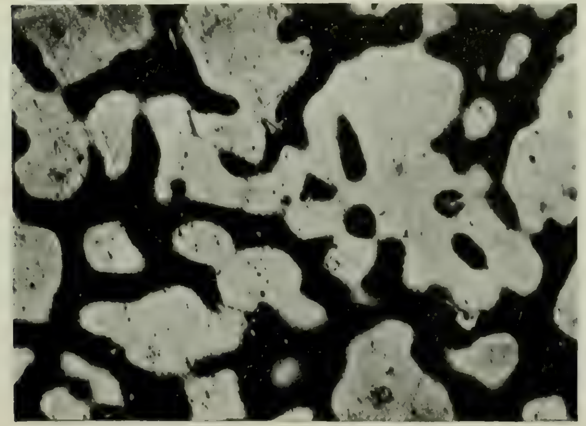


Fig. 8. *Alloy No. 30. × 150 diams.*



Mechanical Engineers 1912.

× 100 diams.

Alloy No. 5. 95% Al. 5% Zn.

Fig. 17. *Sand-Casting.*

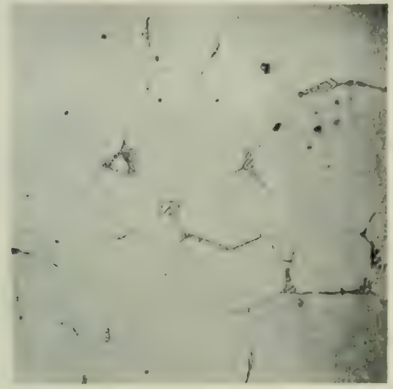
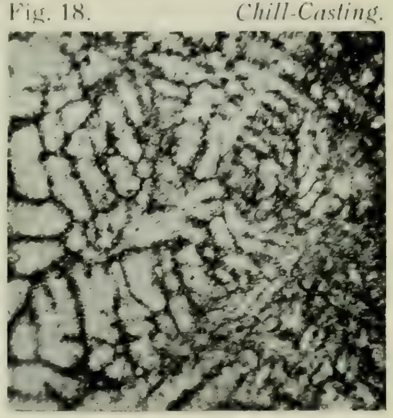


Fig. 18. *Chill-Casting.*



Alloy No. 13.

Fig. 19. *Sand-Casting.*

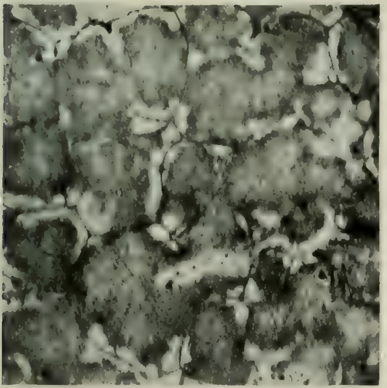
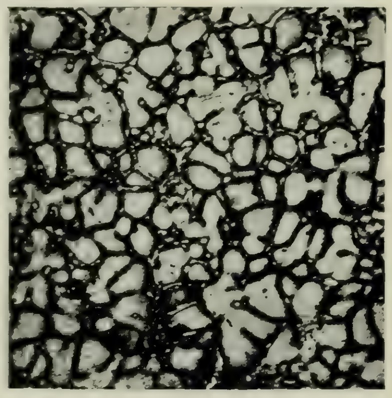


Fig. 20. *Chill-Casting.*



Alloy No. 15.

Fig. 21. *Sand-Casting.*

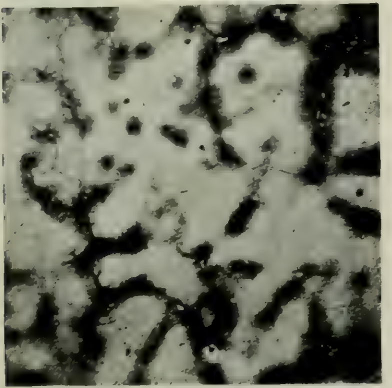
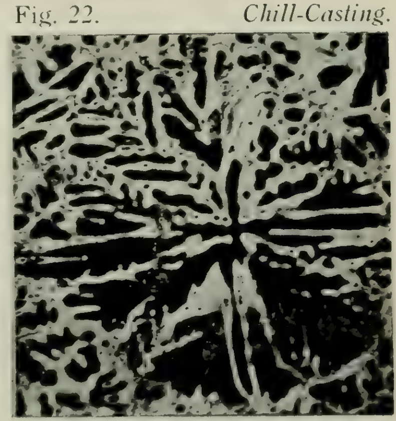


Fig. 22. *Chill-Casting.*



× 100 diams.

Alloy No. 17.

Fig. 23. *Sand-Casting.*

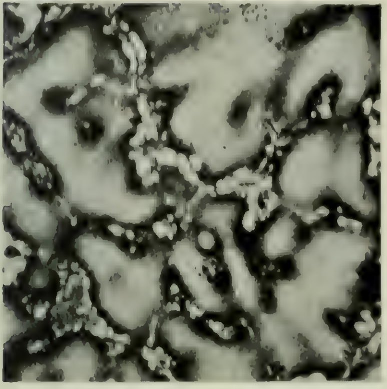
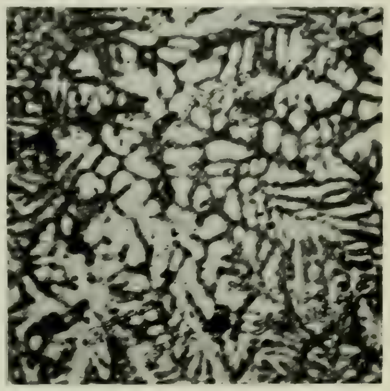


Fig. 24. *Chill-Casting.*



Alloy No. 20.

Fig. 25. *Sand-Casting.*

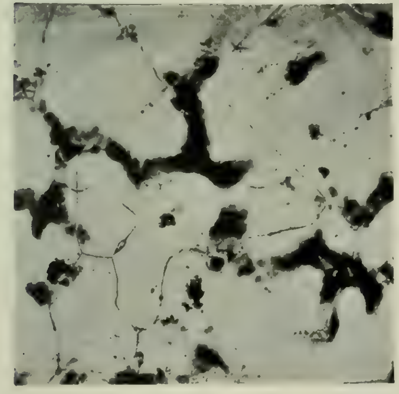
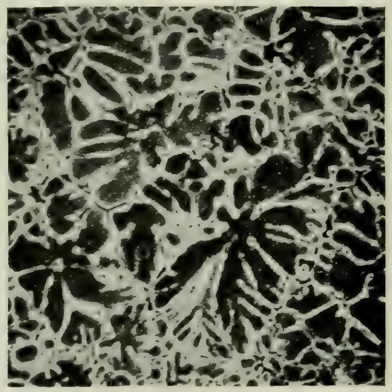


Fig. 26. *Chill-Casting.*



Alloy No. 26.

Fig. 27. *Sand-Casting.*

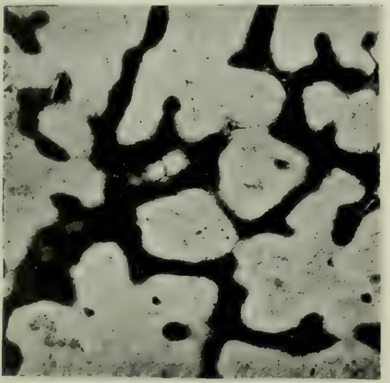
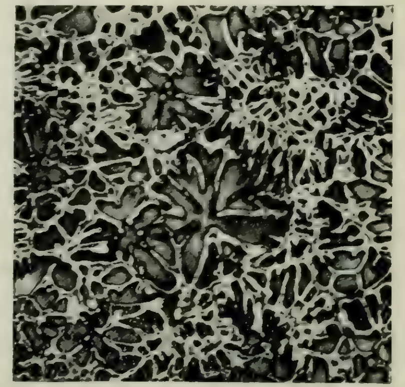


Fig. 28. *Chill-Casting.*



× 100 diams.

Alloy No. 30.

Fig. 29. *Sand-Casting.*

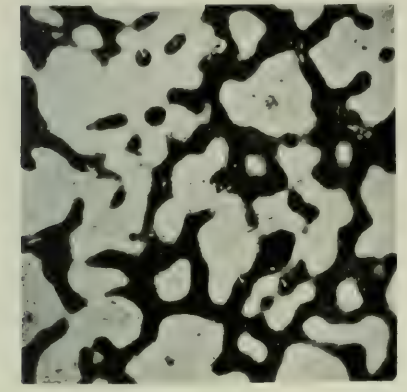
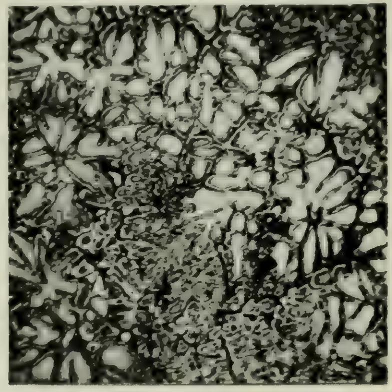


Fig. 30. *Chill-Casting.*



Alloy No. 35.

Fig. 31. *Sand-Casting.*

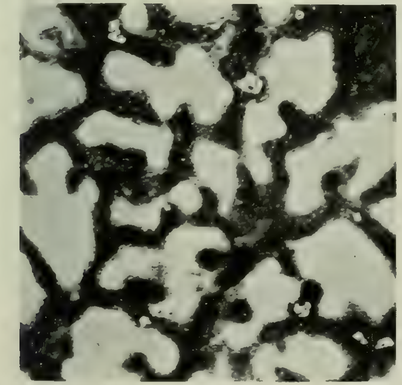
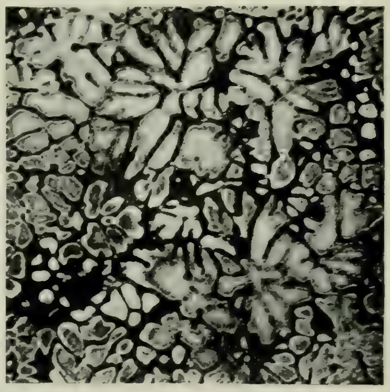


Fig. 32. *Chill-Casting.*



Alloy No. 40.

Fig. 33. *Sand-Casting.*

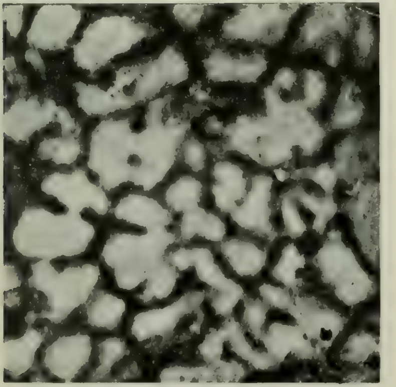
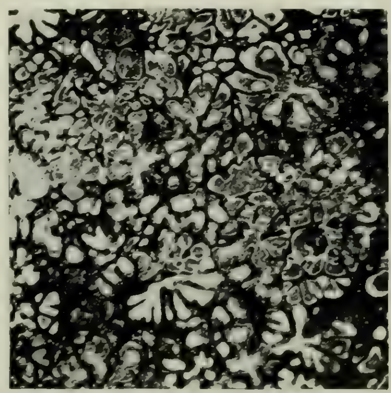


Fig. 34. *Chill-Casting.*



× 100 diams.

Alloy No. 45.

Fig. 35. *Sand-Casting.*

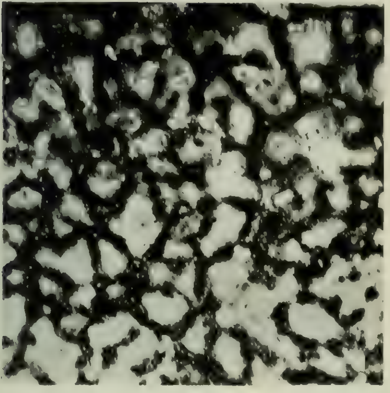
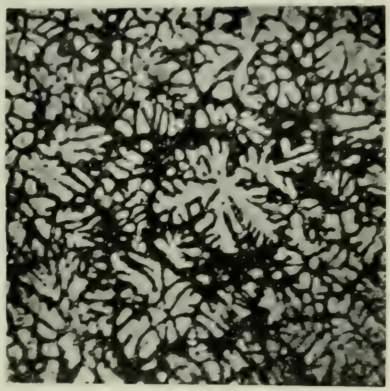


Fig. 36. *Chill-Casting.*



Alloy No. 50.

Fig. 37. *Sand-Casting.*

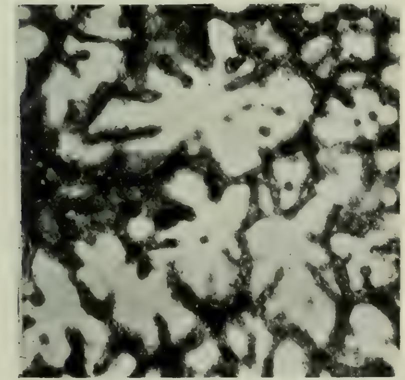
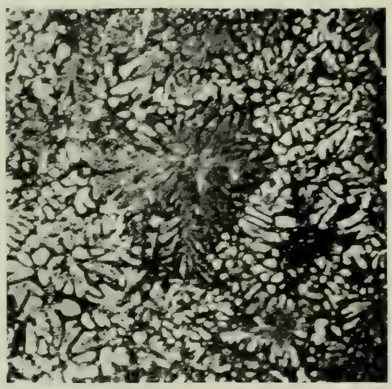


Fig. 38. *Chill-Casting.*



Alloy No. 55.

Fig. 39. *Sand-Casting.*

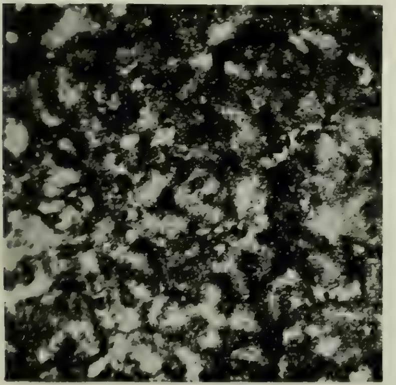
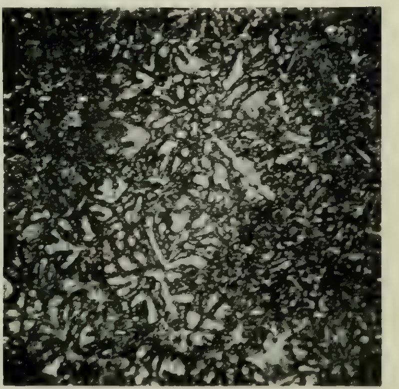


Fig. 40. *Chill-Casting.*



× 100 diams.

Alloy No. 60.

Fig. 41. *Sand-Casting.*

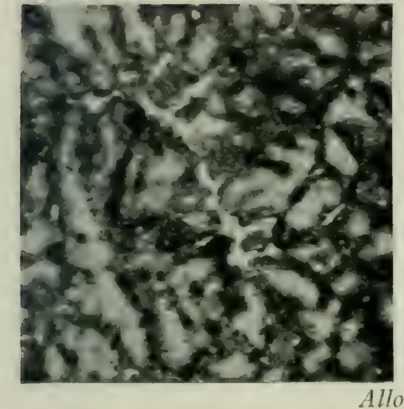
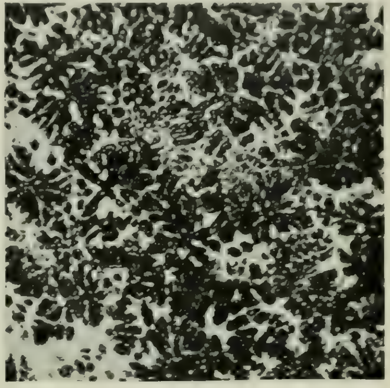


Fig. 42. *Chill-Casting.*



Alloy No. 65.

Fig. 43. *Sand-Casting.*

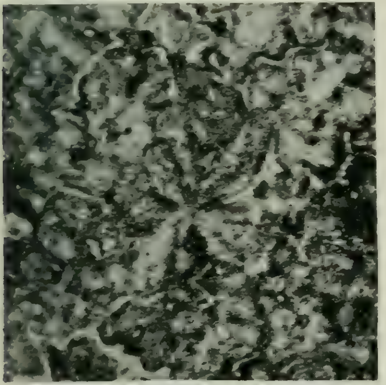
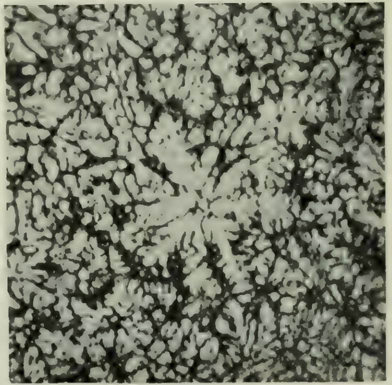


Fig. 44. *Chill-Casting.*



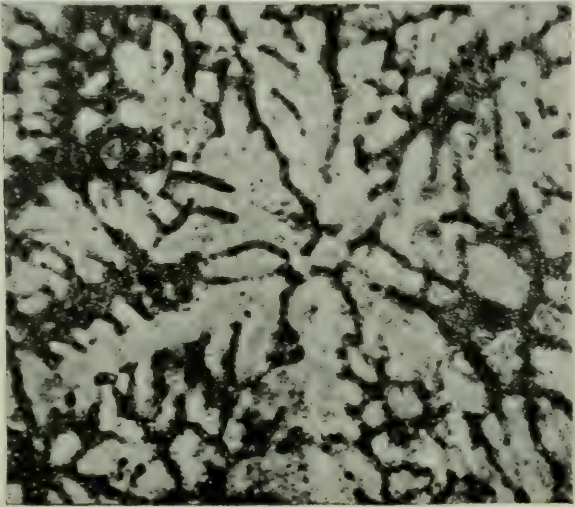


Fig. 44a.

Alloy No. 65.

× 350 diams.

Chill-Casting.

× 100 diams.

Alloy No. 70.

Fig. 45. *Sand-Casting.*

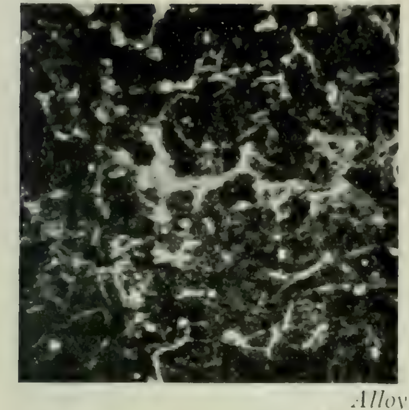
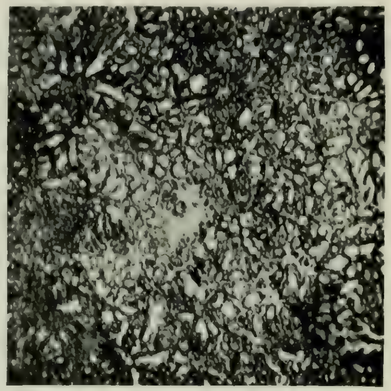


Fig. 46. *Chill-Casting.*



Alloy No. 75.

Fig. 47. *Sand-Casting.*

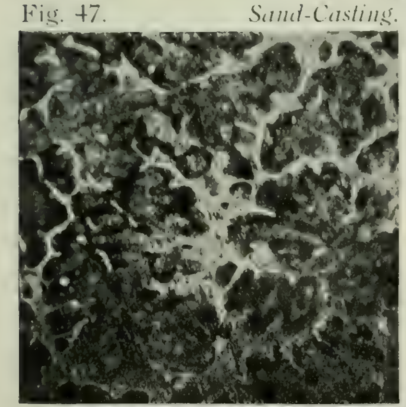
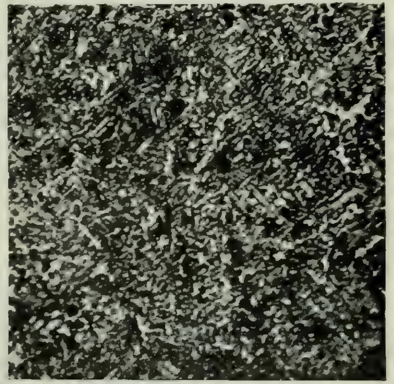


Fig. 48. *Chill-Casting.*



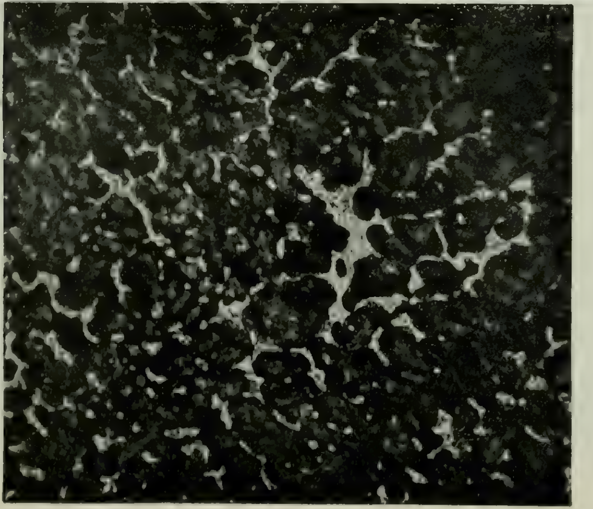


Fig. 48a.

Alloy No. 75.

× 300 diams.

Chill-Casting.

Alloy No. 80. × 150 diams.

Fig. 49. *Sand-Casting.*

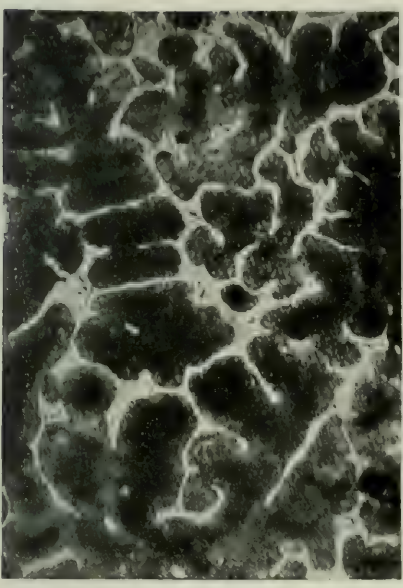
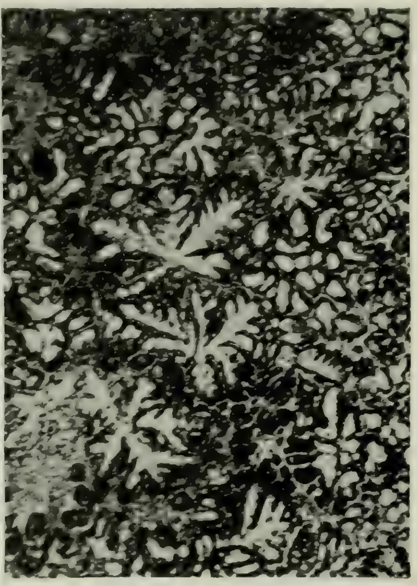


Fig. 50. *Chill-Casting.*



Alloy No. 90.

Fig. 51. *Sand-Casting. × 100 d.*

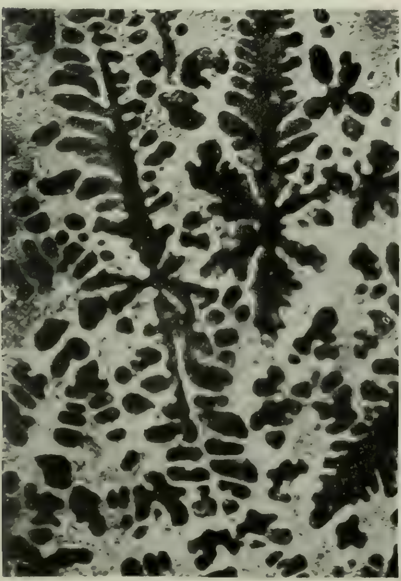
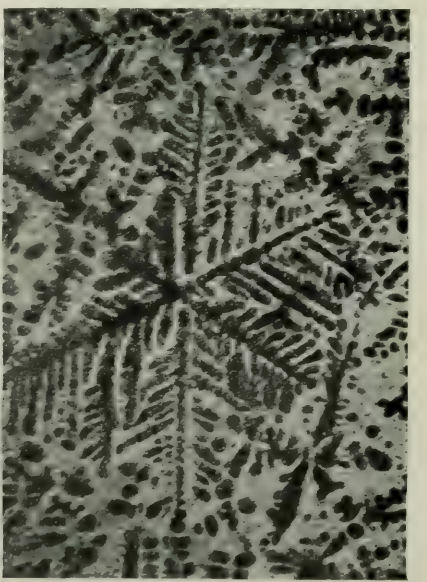


Fig. 52. *Chill-Casting. × 150 d.*



ALLOYS RESEARCH.

× 100 diams.

Alloy No. 5. $\frac{7}{8}$-inch Hot-Rolled Bar.

Fig. 64.

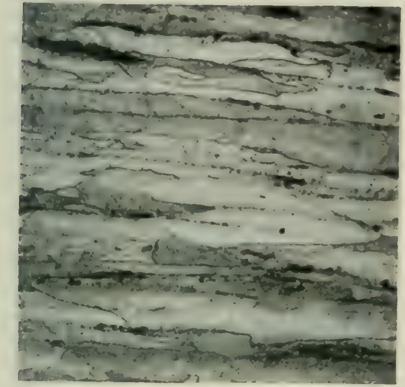
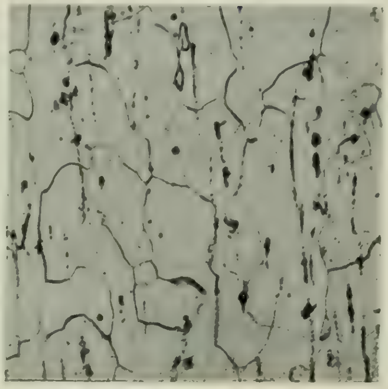


Fig. 65. *Annealed.*



Alloy No. 13. $1\frac{3}{16}$-inch Cold-Drawn Bar.

Fig. 66.

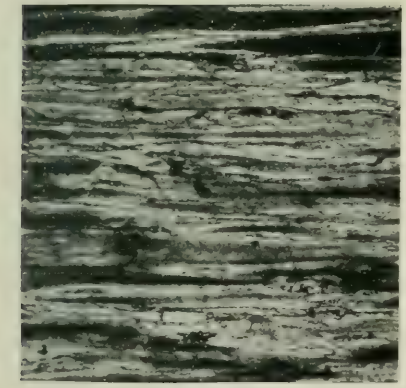
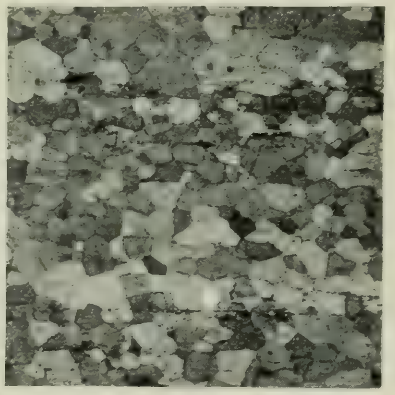


Fig. 67. *Annealed.*



Alloy No. 15.

Fig. 68. *$1\frac{1}{4}$-inch Hot-Rolled Bar.*

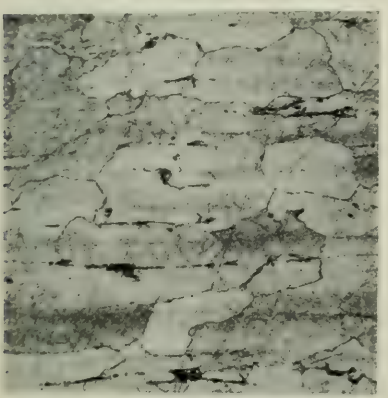
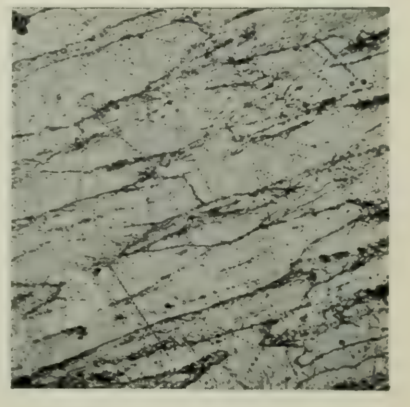


Fig. 69. *$\frac{7}{8}$-inch Hot-Rolled Bar.*



ALLOYS RESEARCH.

Plate 19.

× 100 diams.

Alloy No. 15.

Fig. 70. *$\frac{7}{8}$-inch Hot-Rolled Bar.* *(Annealed.)*

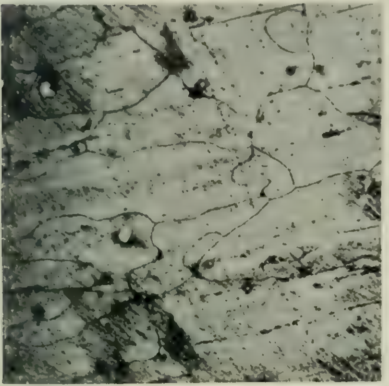
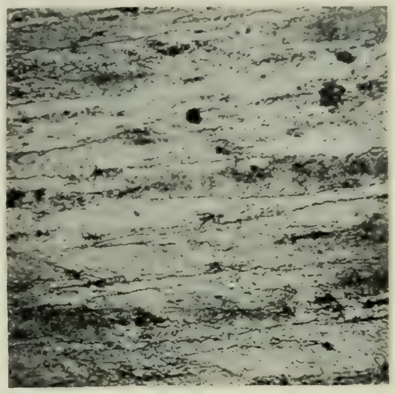


Fig. 71. *$\frac{1}{2}$-inch Hot-Rolled Bar.*



Alloy No. 15.

Fig. 72. *$\frac{1}{2}$-inch Hot-Rolled Bar.* *(Annealed.)*

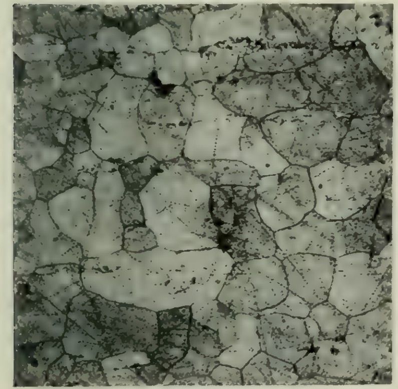
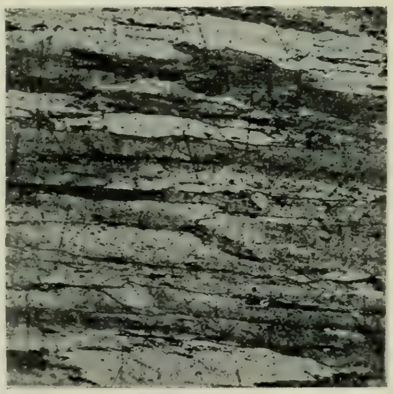
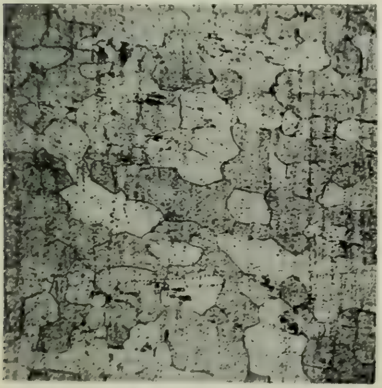


Fig. 73. *$\frac{13}{16}$-inch Cold-Drawn Bar.*



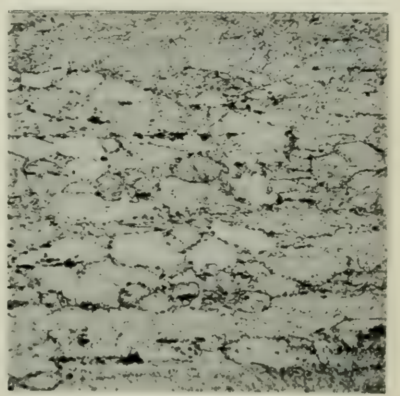
Alloy No. 15.

Fig. 74. *$\frac{13}{16}$-inch Cold-Drawn Bar.* *(Annealed.)*



Alloy No. 19.

Fig. 75. *$\frac{1}{2}$-inch Hot-Rolled Bar.*



ALLOYS RESEARCH.

× 100 diams.

Alloy No. 19.

Fig. 76. *$\frac{1}{2}$-inch Hot-Rolled Bar.* *(Annealed.)*

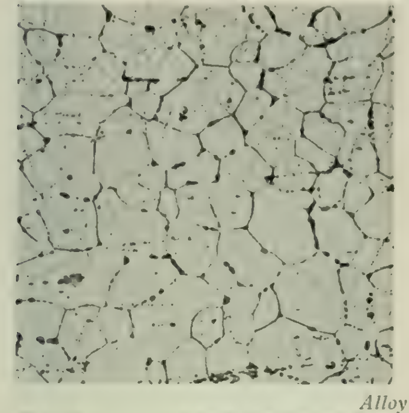
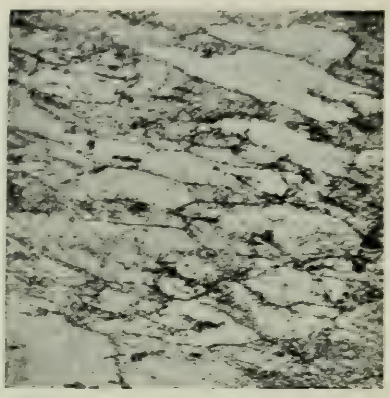


Fig. 77. *$\frac{7}{8}$-inch Hot-Rolled Bar.*



Alloy No. 19.

Fig. 78. *$\frac{7}{8}$-inch Hot-Rolled Bar.* *(Annealed.)*

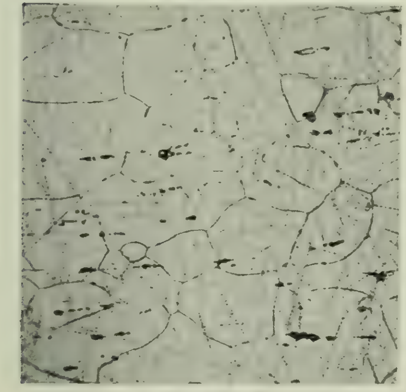
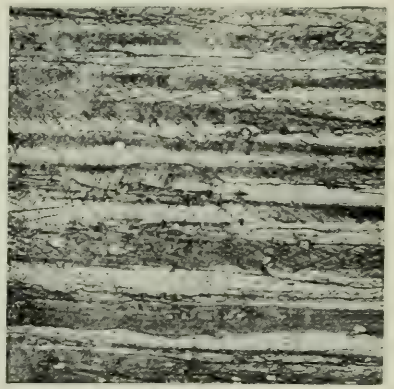
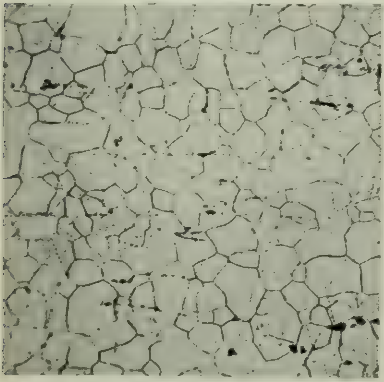


Fig. 79. *$1\frac{3}{16}$-inch Cold-Drawn Bar.*



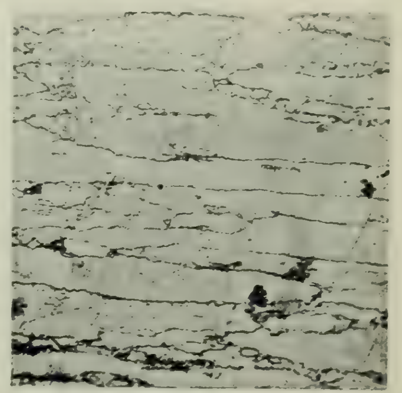
Alloy No. 19.

Fig. 80. *$1\frac{3}{16}$-inch Cold-Drawn Bar.* *(Annealed.)*



Alloy No. 26.

Fig. 81. *$1\frac{1}{4}$-inch Hot-Rolled Bar.*



× 100 diams.
Alloy No. 26.

Fig. 82. *$\frac{7}{8}$-inch Hot-Rolled Bar.*

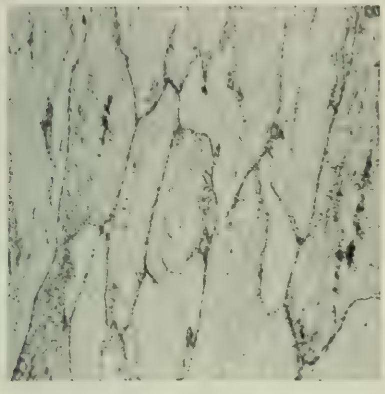


Fig. 83. *$\frac{1}{2}$-inch Hot-Rolled Bar.*

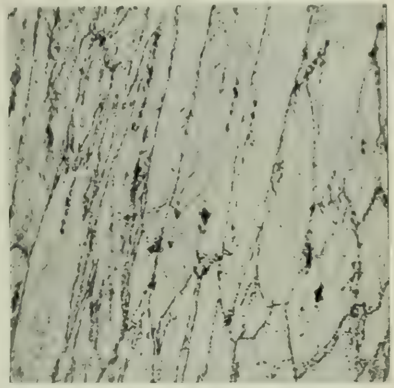
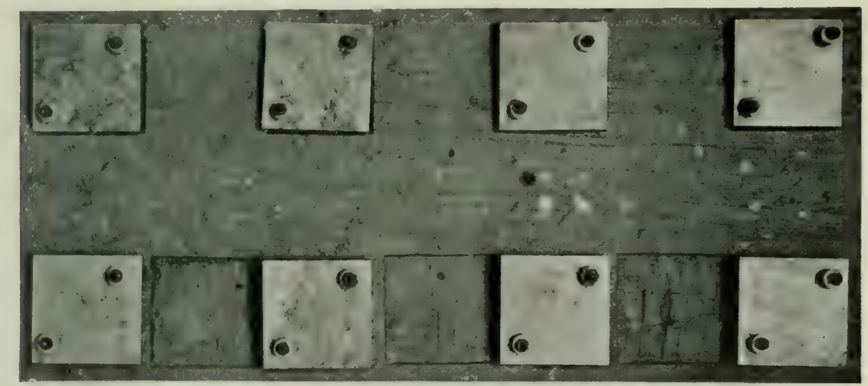


Fig. 105. *Corrosion Test-Pieces.*



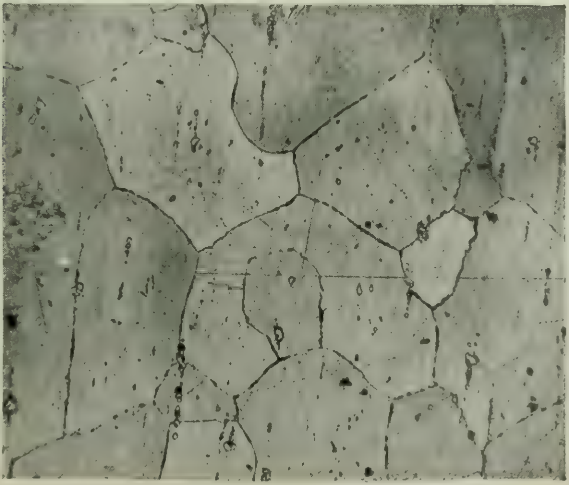
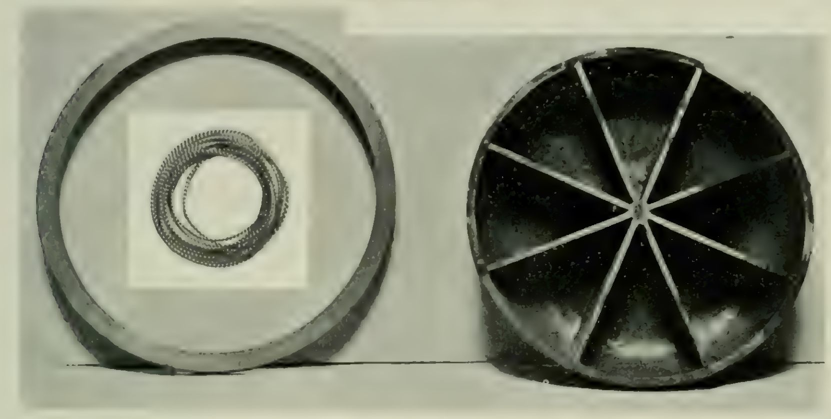


Fig. 107.
Alloy No. 25/3
$\frac{7}{8}$-inch Hot-Rolled Bar.
Heated to 500° C. (932° F.) and slowly cooled.
× 150 diams.

Long Turning taken from one of the present series of alloys (in the rolled condition).

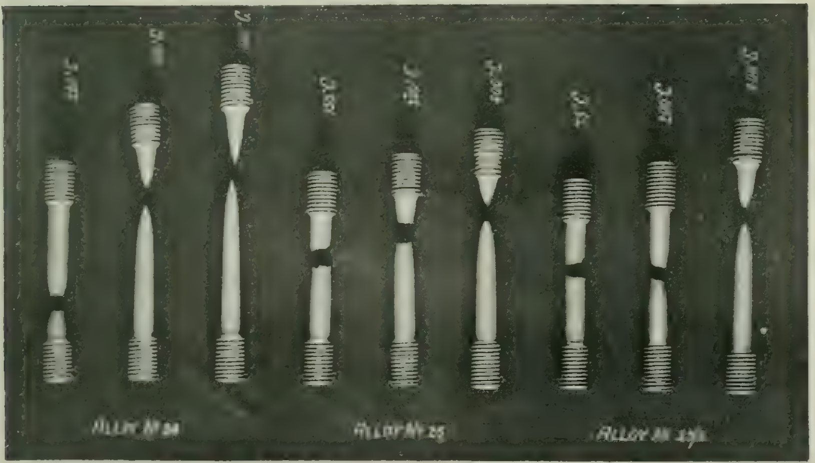
Alloy No. 25. 25% Zn. Two Castings, one rough the other machined.

See page 346.



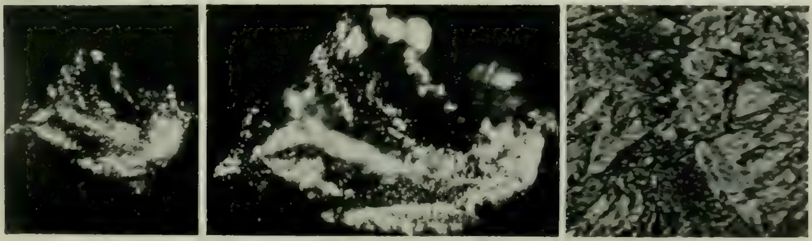
Specimens of Tensile Tests at Various Temperatures.

See "Tensile Tests at High Temperatures," page 416.



(Sir Robert A. Hadfield's communication.)

Fig. 109. *Crystal of Manganese Iron magnified 150, 300 and 750 diams.*



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